CL:AIRE

PFAS SP 01
(July 2026)

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Civil and Military Airfields and Airports.

Civil and Military Airfields and Airports

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO CIVIL AND MILITARY AIRFIELDS AND AIRPORTS

The use of PFAS at civil and military airport and airfield sites (air transport sites) has been responsible for a number of well documented incidents, where release of PFAS at air transport sites has resulted in impact on drinking water (Nordic Council of Ministers, 2019). In 2022, it was revealed that a drinking water supply in the vicinity of a UK airfield had been impacted by PFOS (The Guardian, 2022). Many other cases have been documented around the world where PFAS contaminated groundwater, surface water and soil have been identified in the vicinity of air transport sites. In the UK, at least one airport has been subject to *in situ* remedial treatment of PFAS contaminated groundwater (Regenesis, 2022).

Military airbases have been a particular focus of attention in some countries, with targeted investigations identifying PFAS impacts requiring further management to reduce environmental impacts. In the context of US military sites, it has been observed that "many classes of PFASs are observed in groundwater at essentially every AFFF-impacted site investigated to date" (ESTCP, 2017).

The main source of PFAS at air transport sites is fluorinated fire-fighting foam, released into the environment during training, as accidental releases, and in response to emergency incidents. Reference should be made to the site profile for AFFF (CL:AIRE, 2026l). Particular activities associated with AFFF release to the environment include training grounds, hangar fire suppression systems and runway foaming. Intensive use of AFFF may result in contamination of concrete, which may then become an ongoing source of PFAS, which is leached from the concrete through rainfall runoff (Baduel et al., 2015). The use of AFFF at air transport sites is discussed in more detail below.

Non-polymeric PFAS have been used as additives in aviation hydraulic fluids to prevent evaporation, fires and corrosion (OECD, 2013). In particular, the fully fluorinated 8 carbon cyclic PFAS, perfluoroethylcyclohexane sulfonate (PFECHS), was used in aircraft hydraulic fluids from the late 1940s (MPART and HHWG, 2020). PFECHS has been reported at elevated concentrations in environmental media around the world, and various reports have linked the detection of PFECHS in the environment to its use in aviation in general and at airports in particular (MPART and HHWG, 2020; de Solla et al., 2012).

Additional uses of PFAS in aviation are fluoropolymers such as polytetrafluoroethylene (PTFE), which are extensively used in various mechanical components (e.g. semiconductors, wiring, tubing, piping, seals, gaskets, cables, etc.) (OECD, 2013). PFAS are also used in specialist coatings, as lubricants, and in heat transfer / coolants (Glüge et al., 2020).

The following areas of airports and airfields have been identified with a potential for PFAS use and release:

- Fire training grounds: can include aircraft fire training structures, crash crew staging areas, spray test areas, extinguisher test areas; may also be used for training by local municipal fire services and others;
- Fire stations: storage of foam concentrates and containers; fill points; washdown areas; spray test areas;
- Historical crash or flammable liquid fire locations, and crash debris storage areas; fire tender crash sites;
- Hangars with foam fire suppression systems; foam concentrate substances may be stored in tanks within the hangars; hangar fire suppression systems are reported to have been sensitive to accidental foam release caused by false alarms;
- Hangars where aircraft maintenance is undertaken, mechanical shops where heavy-duty vehicles and appliances are maintained and repaired, with potential release areas of other substances potentially containing PFAS (hydraulic fluids, waxes, greases, hydraulic fluid, specialty paint);

- Areas where the runway was foamed in the past in preparation for hard landings (this is no longer recommended good practice);
- Tank farms/fuel farms with foam fire suppression systems;
- AFFF demonstration areas or areas where foam parties or salutes were conducted;
- Surface water drainage systems and tanks (and sediment), soakaways and effluent discharge points;
- On-site landfills which may have received waste construction materials, soils or sediment impacted by PFAS; and
- Areas of the airport where pesticides or herbicides containing fluorinated compounds are applied (National Academies of Sciences, Engineering and Medicine, 2023).

In 2023, the US National Research Council published a 'PFAS Source Differentiation Guide for Airports' (National Academies of Sciences, Engineering and Medicine, 2023) which is a comprehensive review of PFAS use and characterisation associated with airports in the USA. It provides much useful additional detail on PFAS use within airports, although it should be acknowledged that regulatory requirements and common airport practices may be different in the UK.

2.1 Training Grounds

Fire-fighting training grounds are considered a particular source of AFFF release to the environment at airport sites because of the regulatory requirements for regular live training using foams, and past practice with regard to disposal of effluent from training exercises. The standard set-up for a fire training rig is understood to comprise a fuselage trainer rig on a concrete pad with a fuel supply. Foam may either be provided by mobile fire tenders or from a fixed hose with foam tank. The concrete pad would normally have gully drainage around it, taking effluent to an interceptor and then to the surface water drainage system. The interceptor was intended to remove unburned fuel hydrocarbons. The standard rig was not designed to capture waste AFFF or PFAS. The interceptor would be ineffective at reducing any PFAS from the waste water effluent. After the fire was extinguished, it was common practice to use hoses to flush visible foam to the grassed areas around the concrete pad. Increasing awareness of the environmental risks associated with PFAS has led to a move towards improved containment of waste water so that it can be tankered off site.

Documented examples of environmental impact associated with airport fire training grounds include Ronneby in Sweden, Jersey Airport (Nordic Council of Ministers, 2019) and Guernsey Airport (Ross et al., 2018).

2.2 Runway Foaming

Between the 1960s and the 1980s it was a recognised practice in the UK to divert planes requiring an emergency landing to designated Master Emergency Diversion airfields, where there was equipment to allow foaming of the runway in case of a crash landing, creating a foam 'carpet' or 'blanket'. A Ministry of Defence film documents this practice at Manston in 1965, including the use of a 'Pyrene' runway foamer. The exact composition of these foams is unknown. The Pyrene company manufactured foam fire extinguishers which used carbon tetrachloride (Safelincs Ltd, 2022), but it is not known if this technology was also used for foam blankets. Protein foams were also developed and in use prior to the development of fluorinated foams. Given that the film predates the patenting of PFAS-based AFFF by the US Navy (with 3M), it is assumed that the original Pyrene system was based on earlier non-PFAS foam systems. It seems likely, however, that once AFFFs were available then they would have been used in runway foaming.

No documented examples of environmental contamination associated with runway foaming have been identified. However, the volume of foam required, and dates of operation indicate this could be a potentially significant source.

2.3 Aircraft Hangar Foam Fire Suppression Systems

Aircraft hangars may be fitted with fixed foam fire suppression systems. While in normal use, the likelihood of release of foam from a suppression system may generally be considered low, although release may have occurred during commissioning or system operation tests. There is however evidence that aircraft hangar systems are particularly prone to accidental discharge.

In the USA there is a requirement for fixed foam fire suppression systems in certain types of aircraft hangars, to provide protection from fires including fuel spills. A study was undertaken by the University of Maryland (UMD) in 2019 after concerns were raised over the tendency for these systems to inadvertently discharge causing significant life safety issues, property damage, and major financial and environmental impacts. UMD (2019) surveyed insurance companies, operators, and the National Air Transportation Association. One hundred and seventy-four incident reports of foam discharges were received from 11 sources in the period 2004 – 2019, both in response to fires (37 incidents) and accidental discharges (137 incidents), mostly reported by insurance companies. The majority (85%) of reports received were from the USA. The remaining 15% of reports originated from 8 other (unnamed) countries.

Accidental discharge of foam from hangars can result in substantial environmental damage as the foam is likely to be discharged to surface water drainage systems or to soft ground where infiltration to groundwater may occur. Documented examples of environmental damage associated with accidental hangar foam discharge include Schiphol Airport and Toronto Airport (Nordic Council of Ministers, 2019; Awad et al., 2011).

2.4 PFAS in Concrete, Asphalt and Other Porous Media

There is emerging concern related to the potential for PFAS to impregnate concrete and be released by leaching and desorption following rainfall events for decades after use of PFAS at the site has ceased. Baduel et al. (2015) investigated concrete at a fire training ground in Australia and detected PFAS in a concrete core at depths of up to 12 cm. Desorption studies suggested that leaching of the PFAS from the concrete pad could result in it remaining a source of PFAS for many decades. Another study by Thai et al. (2022) at a fire

training ground, found PFOS both in a concrete core (up to 10,000 µg/kg) and in ponded water on the surface (up to 100 µg/l). Repeated tests with rainfall simulations showed similar maximum concentrations of PFOS, suggesting recurring release of the PFAS from the AFFF impacted concrete.

No documented occurrences of PFAS release from contaminated concrete have yet been identified in the UK.

2.5 Types of Fire-Fighting Foam Used at Airports

There is evidence that some civilian airports in the UK and overseas have consciously moved away from using fluorinated fire-fighting foams. Others maintain stocks of fluorinated foam for emergency use, but use fluorine-free foam for training purposes.

An article published on the Chemical & Engineering News website (Reisch, 2019) indicates that London's Heathrow Airport switched to fluorine-free foams in 2013 after a 15-month evaluation project. The article reports that two incidents at Heathrow Airport in 2013 showed that fluorine-free foams worked as well as fluorine foam. The article suggests that maintenance crews washed the runoff into drains feeding the airport's water treatment plant. A previous incident in 2008, when fluorosurfactant-containing foam was used, is reported to have required collection and disposal of the effluent to prevent release to the environment.

According to the 'PFAS Source Differentiation Guide for Airports' (National Academies of Sciences, Engineering and Medicine, 2023), from the late 1960s until 2019, the US Department of Defense military specification for AFFFs purchased for use at US military sites (MIL-F-24385) required the inclusion of PFAS (fluorocarbon surfactants). Although this military specification MIL-F-24385 was amended in 2019 to remove the requirements for fluorosurfactants in AFFF, the performance specification remained unchanged and could only be met with the use of fluorinated foams (U.S. Department of Defense, 2020). In 2023, a new performance specification for fluorine-free foams was released by US DOD (MIL-PRF-32725) (U.S. Department of Defense, 2023). As stated by the Nordic Council of Ministers (2019), it is reasonable to assume that fluorinated AFFFs conforming to MIL-F-24385 have been used in military airbases in Europe including the UK.

3. CASE STUDIES

Seven sites, identified from literature reviews, were reviewed as case studies with examples of PFAS contamination associated with Civil and Military Airfields and Airports. The findings are listed in Table 1.

4. PROCESS

PFAS may be released into the environment from airfields and airports in the form of surface water runoff and waste water discharge, indirect discharge or leaching to groundwater.

Table 1. Case studies.

1. Ronneby, Sweden
This case study is summarised in a paper by Nordic Council of Ministers (2019). During 2013, water quality monitoring identified elevated PFAS in groundwater at Ronneby, Sweden, and further testing confirmed that treated drinking water at the local municipal water works was also impacted, with PFOS the predominant contaminant, present at up to 8,000 ng/l. As a result, the supply of drinking water was stopped from this location. The source of the contamination was identified as the fire training site at the nearby airport. Fire training activities using PFOS containing AFFF were undertaken at the airport from the mid-1980s. In Sweden, fire-fighting foams containing PFOS were phased out from 2003 to 2008, and Swedish airports and the Swedish military started using fluorine-free alternatives from June 2011. Biomonitoring of the local population showed 20–50 times higher levels of PFAS in exposed individuals compared to a reference group.
2. Jersey Airport, Channel Islands, UK
The airport started using AFFF in training exercises in 1991, in order to meet requirements of UK Airport Fire Services. From late 1991, foam was discharged regularly at the fire training ground and allowed to disperse to groundwater and be washed away by rainwater. In 1993, it was discovered that foaming water was emerging from an excavated land drain in a field associated with a farm to the northwest of the fire training ground (State of Jersey, 2004). At the same time, the private water supply of that farm was discovered to have been contaminated by material giving rise to a brown colouration and substantial foaming. Using both PFOS and PFHxS as indicator compounds the plume was tracked, identifying which watercourses and ponds had been contaminated. Other properties with private water supplies were also affected and had to be connected to mains supply. It was concluded that the most probable source of the contamination was the use of fire-fighting foam for fire training purposes at Jersey Airport's Fire Training Ground (FTG) (Jersey Airport, 2022). Further contamination at the site has been mitigated by discontinuing use of PFOS-containing foams and strict controls over the wash down areas of the FTG. As part of the remediation works there is a programme of monitoring to assess the impact of the remedial works on groundwater quality.
3. Guernsey Airport, Channel Islands, UK
PFAS were identified in the surface waters which supply the island's drinking water reservoir. Concentrations of PFOS detected in the reservoir, were linked back to firefighting foam (AFFF) use at the airport (Ross et al., 2018). PFOS-containing AFFF was used at Guernsey Airport from the 1970s until 2002 when its use was discontinued. Impacted areas included the fire training area, fire station and former fire training area, crash sites and the location of an incident where a fire tender had overturned with the loss to ground of foam concentrate. Most of the remediation work to deal with the PFOS pollution was undertaken as part of a wider Guernsey Airport redevelopment carried out between 2012 and 2014. Large areas of contaminated soil were removed from hotspots within the airfield, and groundwater is now captured and passed through a specially-designed treatment plant to remove PFOS (Ross et al., 2017; PWC, 2016).

Table 1. Case studies (continued).

4. Schiphol Airport, Netherlands
Kwadijk et al. (2014) studied the accidental release of AFFF which took place at Schiphol Amsterdam Airport, also described by Nordic Council of Ministers (2019). In July 2008, an error in the sprinkler-system at a hangar released 10,000 litres of AFFF, containing 143 kg of PFOS, into the surrounding environment. The release spread into waste water reservoirs, which then leaked and caused substantial contamination of soil and surface water. The foam involved was FC-203CF Light Water AFFF, known to contain PFOS (Kwadijk et al., 2014). Although PFBS, PFHxS, and PFOS were monitored, the dominant PFSA found in all samples was PFOS. They conclude that PFSA spills can lead to exceedances of environmental quality standards in the short term, with concentrations remaining elevated even after 3 years (Kwadijk et al., 2014). Nordic Council of Ministers (2019) reported the cost of remediation was estimated as €30–40 million.
5. Hamilton, Ontario, Canada
A study undertaken by de Solla et al. (2012) reported elevated concentrations of PFAS in surface water and biota downstream of Hamilton International Airport in Ontario. PFAS studied included PFCAs, PFSAs, several per- and poly-fluorinated compound precursors (e.g. perfluorooctane sulfonamide, PFOSA), and a cyclic perfluorinated acid used in aircraft hydraulic fluid PFECHS. They concluded that the airport was a likely major source of PFAS contamination in the Welland River, even though there was no known spill event or publicly reported use of AFFF associated with a fire event at the airport.
6. Australian Government Department of Defence
The Australian Department of Defence (DoD) has a PFAS Investigation & Management Program, comprising a national program to proactively review, investigate and implement a comprehensive approach to manage the impacts of PFAS on and in the vicinity of its bases around Australia (Australian Government Department of Defence, 2022). In the interests of transparency, the DoD has made available results of site assessment and testing at their sites. Case studies have also been presented at technical conferences in the UK. Examples include Royal Australian Air Force (RAAF) Base Tindal (Coffey Environments Australia Pty Ltd, 2018), which is located in a remote part of the Northern Territory. The township of Katherine is located on the Katherine River about 15 km north of the base, hydraulically downgradient. In the dry season, groundwater is abstracted for water supply and irrigation, and provides baseflow to the hot springs and the river. Investigation has confirmed that groundwater at the site has been impacted by PFAS, with the primary sources identified as the base fire station and fire training ground, which had been in operation from the 1980s. Minor sources were also identified associated with fuel farms and the mechanical equipment maintenance area. The remote location reduces the likelihood of other potential PFAS sources being present in the vicinity. Further investigation has identified PFOS and PFHxS present in groundwater at concentrations well above drinking water standards (up to 7 µg/l) as far as the town and river located 15 km downgradient from the source, and within springs and water abstraction points. Monitoring shows the river and associated biota are impacted for many kilometres downgradient of the site, with advisories against consumption of fish from the river up to 60 km downstream of the site.
7. Foam incident at a Heathrow Airport Hangar
In May 2020, there were news reports that the fire suppression system in one of the hangars at Heathrow Airport had a technical issue causing foam to be released. Tonnes of foam fire-retardant were sprayed (McShane, 2020). Photos published online show the hangar flooded with foam and also foam dispersed outside the hangar. It is unclear from the news articles what type of foam was released (for example, if it was a fluorinated foam containing PFAS) and what clean-up or containment was implemented. It is noted that, although located within the airport boundary, the hangar is operated by an airline rather than the airport operator. This incident illustrates the reality of the scenario of foam loss through accidental triggering of a foam suppression system in the UK.

Key processes and activities by which PFAS may be released include:

- Use of AFFF in fire-fighting training and emergency response;
- Use of AFFF in fire suppression systems, testing, maintenance and accidental release;
- Accidental spills or loss of AFFF in storage and transport
- Use and loss of hydraulic fluids;
- Use of PFAS in engineering workshops (degreasing, plating, surfactants);
- Release in rainfall events of residual PFAS adsorbed to concrete /asphalt from past activities;
- Discharge to drain or ground of wash water including fire tanks;
- Waste water discharge;
- Discharge of landfill leachate (if landfill is present on site); and
- Application of pesticides and herbicides.

Reference should also be made to the site profiles for Fire-Fighting Grounds and Fire Stations (CL:AIRE, 2026c) and AFFF (CL:AIRE, 2026l).

5. KEY PFAS CONTAMINANTS OF CONCERN

Civil and military airfields and airports have the potential for a wide range of PFAS to be present, with the majority released via AFFF use. Reference should be made to the site profile for AFFF (CL:AIRE, 2026l).

The actual PFAS present at any one site will be variable dependent on the AFFF formulations used, which will have varied over time. While some generalities may be drawn associated with the dates of operation and use, and the date of phasing out of PFOS-based AFFF and the introduction of fluorotelomer chemistry, actual practice varied. Records of AFFF type and composition are also likely to be poor.

One study by Schultz et al. (2004) of three US airbases found markedly different PFAS distribution in groundwater at each of the sites. One site which operated from the 1950s to 1988 had 25% PFSAs and 75% PFCAs. Another site which had been operational from 1980 – 1992 had 82% FTS, 16% PFSAs and only 2% PFCAs, implying contamination from fluorotelomer based AFFF. A third site

which had been operational from the 1950s until 1993 showed varied PFAS present at different locations around the site including FTS, PFCA and PFSA.

The fingerprint relating to the relative distribution of PFAS may be used to investigate and differentiate multiple sources of PFAS release. The type of AFFF used by the US Department of Defense is controlled by Military Specification (MILSPEC), which means that in the USA it may be possible to differentiate some AFFF from military sources from other sources based on the PFAS signature (Higgins, 2021). Similar controls on foam procurement and supply are not known to have existed within particular sectors in England, and therefore differentiation between AFFF sources may be more difficult.

The 'PFAS Source Differentiation Guide for Airports' (National Academies of Sciences, Engineering and Medicine, 2023) includes a detailed review of PFAS data related to airports and other sources in the USA, and proposes PFAS composition may be used to aid source differentiation between airport derived sources of PFAS and other sources. This provides much useful information and insight into the challenges associated with forensic analysis of PFAS. It should be noted that the airport practice and different regulations and supply chain may mean that some findings may be less applicable in the UK.

The fully fluorinated cyclic PFAS PFECHS was marketed for use in aviation hydraulic fluids and has been associated with air transport sites.

6. SOURCE POTENTIAL FOR CIVIL AND MILITARY AIRFIELDS AND AIRPORTS

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

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Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Old fire-fighting training grounds and practice areas	5	5	25	Historically foams were used directly on the ground and in pits where fire was staged for training. Large quantities of AFFF were used and released to the ground with high frequency. Currently this practice is improved and runoff likely to be contained, therefore the source potential of 25 is related to the old practice and can be reduced in more recent fire-fighting training grounds.
Hangars with foam fire suppression systems	5	4	20	Foam likely to be released during tests of the fire suppression system and/or malfunction. Hangar suppression systems have been identified as particularly prone to accidental discharge compared to other fire suppression systems. Foam is stored in tanks within the hangar and used in case of fire emergency, spraying from the ceiling.
Waste water system	3	5	15	Runoff of waste water from paved areas is collected by drains. The waste water runoff can contain PFAS if an uncontrolled release of PFAS containing material has occurred on a paved area. PFAS may be absorbed into concrete drains and act as an ongoing source of PFAS after use has ceased on a site. Oil water separators, where present in the waste water system, are ineffective in retaining the PFAS. Waste water may be collected and discharged via on-site or off-site waste water treatment works which may not have been designed to treat for PFAS.
Crash sites (planes and fire engines)	5	2	10	Historically foam was used directly on the ground and in unprotected areas with runoff released to the ground or collected by drains. Currently this practice is improved and runoff is more likely to be contained.
Vehicle washing area	2	5	10	Area where fire engines are washed, and tanks rinsed. PFAS containing materials can be released to the waste water or used in cleaning products.
Landfills	3	3	9	On-site landfills which may have received waste construction materials, soils or sediment impacted by PFAS. Leachate can contain PFAS and potentially impact the groundwater.
Fire stations	2	4	8	Foam containing PFAS stored in tanks within fire stations, fire engines and pumps at vehicle fill points. Release to the environment may be via accidental spills. It is considered that relatively low quantities of PFAS will be released in these areas. Current tanks may be provided with leak alarms and fire engines with sophisticated systems to avoid spills.

Table 2. Site Profile Zone Source Potential (continued).

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Areas where the runway was foamed in preparation for hard landings	5	1	5	Foam taken from fire station to the runway area via fire engines and tanks. Tests of the application system may have been done on unpaved ground. Repeated application before the hard landing, foam washed to ground after use. Runway foaming is no longer considered good practice.
Tank farms/fuel farms	5	1	5	Fuel farms likely to have foam fire suppression systems. Foam is stored in tanks. Major release during accident. Minor release from accidental spills from the tanks. Foam released due to accidents or testing is likely to be collected and discharged via drains and/or oil water separator to a WWTW.
Surface water drainage systems and tanks soakaways and effluent discharge points	1	3	3	Sediments likely to be contaminated by PFAS and to slowly release PFAS to the water environment. Waste water treatment processes may not have been designed to treat PFAS.
Hangars and mechanical shops where maintenance of aircraft, heavy-duty vehicles and appliances is undertaken	1	2	2	Replacement of airplane components, hydraulic fluid, and application of waxes, greases, and specialty paint. Considered likely to be low quantity.
Concrete or other semi porous hardstanding areas where PFAS have been used	1	2	2	Past adsorption of PFAS to concrete and other semi-porous surfaces. Slow release of PFAS from concrete can potentially impact surface water and groundwater.
Areas where pesticides or herbicides are applied	1	1	1	PFAS contained in herbicides and pesticides and likely to be spread within the site as ground control routine. Accidental release of mixture containing PFAS may occur in the pesticides storage area. Considered to be low quantity.

IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Control of Major Accident Hazards (COMAH) Regulated Sites.

Control of Major Accident Hazards (COMAH) Regulated Sites

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);

- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO COMAH REGULATED SITES

This site profile refers to sites in England which are classified as COMAH sites under The Control of Major Accident Hazards Regulations 2015 (COMAH Regs., 2015). It also considers sites which were formerly classified as major hazard sites under previous regulations including Notification of Installations Handling Hazardous Substances Regulations (NIHHS) 1982 (NIHHS Regs., 1982) and Control of Industrial Major Accident Hazards (CIMAH) Regulations 1984 (CIMAH Regs, 1984).

COMAH sites include sites using and storing flammable substances, and the COMAH Regulations require the provision of fire protection and prevention measures, and the testing of emergency plans for some sites. Fluorinated fire-fighting foams including PFAS are likely to have been in use on such sites, and testing requirements mean that PFAS are likely to have been lost to ground. It should be emphasised that fluorinated foams will not have been required to be used at all COMAH and related sites, the designation is used for preliminary screening to identify possible PFAS source sites.

COMAH sites include a diverse range of activities, many of which have been identified as potential PFAS source site types meriting their own site profiles; these include Refineries and Fuel Sites (CL:AIRE, 2026i) and Waste Water Treatment Works (CL:AIRE, 2026k) (reference should be made to the relevant site profiles). Reference should also be made to the site profiles for AFFF (CL:AIRE, 2026l) and Fire Suppression Systems (CL:AIRE, 2026m).

This site profile has been developed based on the collation and review of readily available published information and has not included any interviews or assessments of any specific sites in England.

2.1 Current COMAH Regulations

The purpose of the COMAH Regulations is to prevent major accidents involving dangerous substances and they aim to limit the consequences to people, local communities and the environment of any accidents which do occur. The COMAH Regulations are enforced by a competent authority comprising the Health and Safety Executive (HSE), or the Office for Nuclear Regulation (ONR) for nuclear establishments, together with the Environment Agency (in England).

The COMAH Regulations apply to establishments having any dangerous substances specified in Schedule 1 of the regulations and present at or above the qualifying quantity, both singularly or in aggregation. There are two thresholds, known as lower tier and upper tier, based on the quantity, in tonnes, of the dangerous substances in the site inventory. Dangerous substances are defined using the Classification, Labelling and Packaging Regulation 2008 (CLP) (CLP, 2008). Relevant hazard categories include health hazards (such as acute toxicity), physical hazards (such as explosivity and flammability) and environmental hazards.

Regulation 7 (COMAH Regs., 2015) requires every COMAH operator to prepare and keep a document setting out their major accident prevention policy (MAPP).

Operators of upper tier COMAH establishments must also prepare a safety report. Its purpose is to show that the operator has put in place arrangements for the control of major accident hazards and to limit the consequences to people, local communities and the environment of any that do occur. The safety plan should include details of prevention, control and mitigation measures in place to minimise the impact of an incident, which are likely to include fire suppression systems and containment systems, including mobilisable resources such as for secondary containment.

The operator must also prepare an internal emergency plan and consult with relevant stakeholders. The local authority must prepare an external emergency plan, in consultation with the operator,

competent authority and emergency responders. The emergency plans need to detail the measures required to deal with emergencies, for example fire-fighting, including the types of equipment and materials required (such as foam). This necessitates consultation with the emergency services to confirm that adequate arrangements are in place, such as adequate stocks of the required fire-fighting equipment (including foam). It also requires consultation with the Environment Agency in connection with mitigating impacts on the environment from the response to the emergency.

The regulations also require that Upper Tier operators "must at suitable intervals not exceeding three years – (a) review and, where necessary, revise the internal emergency plan; and (b) test the plan." An emergency plan test is undertaken to give confidence in the accuracy, completeness and practicability of the plan. Testing an emergency plan may consist of a live exercise or a table-top exercise supported by the testing of other components. A live exercise involves the deployment on the ground of the appropriate resources in a simulation of their actual response to an accident. Live exercises are likely to include practical testing of fire-fighting equipment. While recent and current testing of fire-fighting capability is likely to use fluorine-free training foam, it is likely that past exercises will have used fluorinated foams.

The Chemical and Downstream Oil Industries Forum (CDOIF) Environmental Risk Tolerability Guideline (CDOIF, 2020) provides a common methodology by which environmental risk assessments for establishments subject to COMAH Regulations can be carried out to demonstrate environmental risk has been reduced to a tolerable level.

2.2 Former Major Hazard Regulations (COMAH Predecessors)

The first onshore major hazards specific regulations were the Notification of Installations Handling Hazardous Substances Regulations (NIHHS) 1982 (NIHHS Regs., 1982), which required notification to the HSE for the handling of certain hazardous substances above specified thresholds. These regulations are still in force today but have mostly been superseded by subsequent legislation. The NIHHS (1982) regulations did not include any specific requirement for provision of emergency measures.

The Control of Industrial Major Accident Hazards (CIMAH) Regulations were introduced in 1984 (CIMAH Regs, 1984) and implemented the Seveso Directive 82/501/EEC (EEC, 1982). Operators of the most hazardous sites which were termed 'top tier' sites, were required to provide HSE with information on how their installations were designed, constructed and operated safely. This included the requirement for provision of an emergency plan, but no specific requirements associated with training exercises or fire-fighting provision.

The Control of Major Accident Hazards (COMAH) regulations were introduced in 1999; including the 'Competent Authority' (CA) and required operators of COMAH sites to submit safety reports to the CA, together with additional information, including emergency planning and training. There was a requirement "to prepare, test and review emergency plans to respond to such emergencies".

2.3 PFAS Use Within COMAH Sites and Former COMAH Sites

A major use of PFAS within COMAH sites is likely to be associated with the use of fluorinated AFFF (refer to the site profile for AFFF (CL:AIRE, 2026l). Fluorinated AFFF use on COMAH sites may be associated with fire suppression systems, on-site fire stations, stocks of fire-fighting equipment, and fire training, including live exercises as required under the COMAH Regulations. While fluorine-free training foam may now be specified for use in exercises, if the equipment is also used for incident response with fluorinated foam, some cross-contamination may occur.

Due to the varied nature of the dangerous substances which may lead to the designation of a site as a COMAH site, not all COMAH facilities will necessarily have a requirement for foam for fire-fighting. Foams are however likely to be a requirement for all sites with flammable substances (class B fires) and may also be used on sites with an inventory of dangerous substances under other hazard categories.

PFAS may also be used within specialist process activities in some COMAH sites, for example chemical manufacture and storage.

The COMAH Regulations and associated inspections (termed as 'interventions') by competent authorities, including the Environment Agency, mean that current and future activities on Upper Tier COMAH sites are well regulated. Mitigation should also be in place to protect and prevent impact on the environment to as low as reasonably practicable (ALARP), as long as the operators and regulators are aware of the risks associated with PFAS from AFFF. This awareness may, however, not always be present, particularly in the case of fluorinated AFFF based on C6 technologies which are marketed as 'environmentally mindful' and do not make clear that, while they do not contain PFOS and PFOA, they may contain other PFAS including PFSAs, PFCAs and their precursors. There may also be limited awareness of the ineffectiveness of interceptors in the removal of PFAS and the unsuitability of discharge of PFAS-containing effluent to sewer.

In reality, detailed environmental risk and tolerability assessments roughly following CDOIF guidance, focus on 'dangerous substances' within the total site inventory which meet the E1 & E2 Environmental Hazards listed in Schedule 1 (COMAH Regs., 2015). PFAS, other than PFOS, are not currently classed as 'dangerous substances' and will not therefore be considered.

3. CASE STUDIES

One case study was reviewed and the findings are listed in Table 1. See also the site profile for Refineries and Fuel Sites (CL:AIRE, 2026i) for examples of case studies of similar sites outside the UK.

PFAS Site Profile

Table 1. Case study.

1. Foam incident at a site in England
The potential accidental release of PFAS at COMAH sites can also occur due to system failure. One such incident was reported at a site in England in 2020. The operator was reported as noting a leakage of the 'underground foam ring main system' which occurred during routine testing of the fire protection system. Some of the foam leaked into the surface water drainage system which discharges to the local estuary. Although the leakage to the drainage system was spotted quickly and stopped within 30 minutes, it was estimated that up to 2 tonnes of foam and water had been released to the drainage system and estuary. The foam in question was identified as a 'C6' AFFF that does not contain the regulated PFOS or PFOA. It is, however, a fluorinated foam containing 6:2 FTS, which is a precursor of PFHxA and other PFAS.

4. OVERVIEW

The requirements of the COMAH Regulations for accident protection, prevention and testing of emergency plans, mean that PFAS use and loss to ground is likely in Upper Tier sites which were in operation prior to increased awareness of the environmental risks associated with PFAS. Upper Tier COMAH sites using and storing flammable substances are likely to have used fluorinated AFFF in live training exercises, as well as in response to incidents, and past practice is likely to have included flushing of foams to ground and to sewer.

Historically, many major hazard and COMAH sites had their own fire stations and fire fighters present on site, and will have undertaken their own training on site. Nowadays many sites rely on external emergency services.

Lower Tier COMAH sites are likely to have a similar use of PFAS in fire suppression systems and associated with incidents or spills. However, without the requirement for live test exercises, the likelihood of regular active use of fluorinated foams at Lower Tier sites, is expected to be lower.

5. PROCESS

PFAS may enter the environment at COMAH sites through the use of fluorinated AFFF associated with fire-fighting, fire training and fire suppression systems, storage of concentrates and discharge of firewater.

Reference should also be made to the site profiles for AFFF (CL:AIRE, 2026l) and Fire-Fighting Grounds and Fire Stations (CL:AIRE, 2026c).

6. KEY PFAS CONTAMINANTS OF CONCERN

A wide spectrum of PFAS precursors and arrowhead products may be present associated with AFFF use, storage and loss to the environment at COMAH sites.

Wood Environment and Infrastructure Solutions (2020) list the following PFAS associated with AFFF:

- PFSAs: C2 – C11;
- PFCAs: C4 – C14 and C18;
- Various perfluoroalkane sulfonyl fluoride substances (PASF) and derivatives including sulfonamides (e.g. FBSA, FOSA), sulfonamidoacetic acids (e.g. FOSAA, EtFOSAA) and sulfonamidoethanols (e.g. FOSE, EtFOSE); and
- Fluorotelomers: 22 substances including sulfonates, alcohols, betaines, etc.

The actual PFAS present at any one site will vary dependent on the AFFF formulations used, which will have varied over time. While some general conclusions may be drawn associated with the dates of operation and use, the date of phasing out of PFOS-based AFFF and the introduction of fluorotelomer chemistry, actual practice varied. Records of AFFF type and composition are also likely to be poor.

PFAS may also be used within specialist process activities in some COMAH sites, for example chemical manufacture and storage.

7. SOURCE POTENTIAL FOR COMAH SITES

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Emergency exercise areas	5	5	25	Foam use when testing systems and practicing emergency response. Historically foams were used directly on the ground and in pits where fire was staged for training. Large quantities of AFFF were used and released to the ground with high frequency. Currently this practice is improved and runoff likely to be contained, therefore the source potential of 25 is related to the old practice and can be reduced in more recent exercise areas.
Waste Water System	3	5	15	Runoff of waste water from paved areas is collected by drains. The waste water runoff can contain PFAS if an uncontrolled release of PFAS containing material has occurred on a paved area. Oil water separators present in the waste water system are ineffective in retaining the PFAS substances.

Table 2. Site Profile Zone Source Potential (continued).

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Vehicle washing area	2	5	10	Area where fire engines are washed and tanks rinsed. PFAS containing materials can be released to the waste water system or used in cleaning products.
Fire suppression systems	3	3	9	Foam fire suppression systems may be a source of release during testing and maintenance, system failure, or accidental triggering. In the past, testing is likely to have required active release of foam. Foam released due to accidents or testing is likely to have been collected and discharged via site drainage system. Even if foam suppression systems have been converted to be PFOS-free or fluorine-free foams, there may still be carryover of PFAS from previous foams used.
Fire stations	2	4	8	Foam containing PFAS stored in tanks within fire stations, fire engines and pumps at vehicle fill points. Release to the environment may be via accidental spills. It is considered that low quantities of PFAS may be released at these locations. Current tanks may be provided with leak alarms and fire engines with sophisticated systems to avoid spills.
Tank farms/fuel farms	5	1	5	Fuel farms are likely to have foam fire suppression systems with foam stored in tanks. Major releases may occur during an accident with minor releases from accidental spills from the tanks or during system tests.
Surface water drainage systems and tanks soakaways and effluent discharge points	1	3	3	Sediments are likely to be contaminated by PFAS and to slowly release PFAS to the water environment. Below ground drainage networks can sometimes form part of the containment system on site during an emergency.
Concrete or other semi-porous hardstanding areas where PFAS have been used	1	2	2	Past adsorption of PFAS to concrete or other surfaces. Slow release of PFAS from concrete can potentially impact surface water and groundwater.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Fire-Fighting Grounds and Fire Stations.

Fire-Fighting Grounds and Fire Stations

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO FIRE-FIGHTING GROUNDS AND FIRE STATIONS

Fire-fighting grounds and fire stations are locations where AFFF may have been used and stored.

2.1 Fire-Fighting Grounds

Fire-fighting grounds are locations where AFFF have likely been applied in large amounts and directly to the ground, potentially over a long period of time. For example, the fire training centre at Moreton-in-Marsh (Fire Service College, 2019) includes areas described as suitable for foam training with dedicated drainage. Typical areas used as foam training areas include:

- Bunded Fire Trays and Live Fire Areas, for live fire (petrochemical or carbonaceous) and chemical demonstrations;
- Fire Behaviour Demonstration Units;
- Liquefied Petroleum Gas (LPG) Fire Screen and LPG split flange with a bunded area;
- A realistic four-lane motorway used for replicating fires from accidents and oil spills;
- An oil rig used to practice fighting a range of different fire and rig incidents involving LPG and oil fires; and
- Static tanks with a bunded training area.

The following areas within fire stations and fire-fighting grounds are identified as areas where PFAS use may occur:

- Training areas where foam has been used to extinguish petrochemical fire (oil rig, static tanks, bunded fire trays and live fire areas and motorway fires);
- Vehicle maintenance and tank washing areas;
- AFFF concentrate and bulk storage areas;
- Vehicle fill points; and
- Vehicle parking areas / garage for foam producing vehicles.

2.2 Fire Stations

The size and location of current fire stations often determine the storages of foams. Typical storage of foams is likely to be in outdoor tanks with leak detectors (depending on the modernity of the fire station). The amount of foam stored is generally proportioned on numbers of engines present in the fire stations. It is typical for smaller fire stations to refer to a foam refill centre for filling the engines with AFFF instead of on-site foam storage.

Generally, no tests or physical training exercises using foam are undertaken within fire stations. However, spills of AFFF can occur from tanks and pipe connections.

Historically (in England only) specific sites were designated as training sites (where training with fluorinated foam might have taken place) or foam sites (where foam concentrate would be stored). However, other equipment or appliances that were used for the deployment of foam could be cleaned or maintained at sites not designated as foam or training sites. These sites and activities result in the potential for loss to ground of AFFF.

3. CASE STUDIES

Three sites were reviewed as case studies with the findings listed in Table 1.

Table 1. Case studies.

1. Fire station in England
The site is a former fire station which was recently investigated as part of proposals for redevelopment. The site was in use as a fire station from circa 1960s until 2014. Anecdotal records from Fire and Rescue Service (FRS) suggested no AFFFs were used in training on the site or were stored on the site. A ground investigation undertaken to inform the redevelopment found localised PFAS impact on soils and groundwater interpreted as the result of loss through leaky drains and cracks in the concrete. This case study highlights the real potential for discernible PFAS impact on fire station sites where AFFF has not been known to be used or stored, although activities may have taken place which can result in AFFFs entering the ground, such as cleaning equipment/vehicles, storage of AFFF concentrate, tank filling and other activities. Review of publicly accessible planning data has identified several other relatively small former urban fire stations in England where investigation during recent site redevelopment has identified PFAS impact on ground and/or groundwater requiring localised remediation.
2. Fire-fighting training area in France
A case study of PFAS contamination at a Fire-fighting Training Site in France is presented in Dauchy et al. (2019a; 2019b). 43 water samples were collected from various areas within a large fire-fighting training site, including effluent from a waste water treatment plant (WWTP), lagoon, runoff water, and waste water drained from firefighter training areas. The purpose of this study was to evaluate the occurrence of more than 50 PFAS in 43 water samples. PFCAs with more than seven perfluorinated carbons were only quantified in waste water drained from the firefighters' exercise areas and runoff water samples with the highest total PFAS concentrations. They also found that a comparison of the PFAS classes analysed revealed the overwhelming contribution of fluorotelomers. This indicates that the PFAS emission from the use of fire-fighting foams cannot be monitored only by measuring perfluoroalkyl acids. Dauchy et al. (2019a) also stated that previously published studies have also shown that water samples collected close to fire drill areas contain long-chain PFCAs, such as PFNA, PFDA, and PFUnDA. It is likely that these PFCAs are not intentionally added to some foams but are present as impurities. In the lagoon, total concentrations of quantified PFAS remained similar from one sampling event to another, and were consistent with the concentration measured in the runoff water network just upstream of the lagoon. The relative contribution of fluorotelomers to the total PFAS concentration was always 94%, indicating that almost no transformation occurred in the lagoon (Dauchy et al., 2019a).
3. Fire-fighting training area in Korsoer, Denmark
A case study of a fire-fighting training area in Denmark was presented by Harrekilde (2022). The PFAS contamination was first identified due to elevated PFOS (975 ng/l) in discharges from the local water treatment works, and traced back to the local fire training school located in a predominantly rural area. Further investigation found elevated PFOS in waste water pipelines, and in the sediment in a ditch receiving surface water runoff. PFOS was also detected in meat from cattle grazing near the ditch, and moderately elevated PFOS was measured in the blood samples from people who had been eating the local beef. The case triggered a widespread media response, and initiation of a programme to investigate other fire training grounds across Denmark, with the designation of a list of 180 sites.

4. PROCESS

Key processes and activities by which AFFF may be released into the environment from Fire Stations and Fire-Fighting Grounds include:

- Use in training exercises including practice emergency response;
- Large volume accidental loss through systems failure;
- Low volume accidental release during storage, transfer and maintenance;
- Incident and emergency response;
- Discharge to drain or ground including vehicle wash water;
- Controlled or uncontrolled waste disposal; and
- During rainfall events, slow release of AFFF previously adsorbed to concrete during prior release.

5. KEY PFAS CONTAMINANTS OF CONCERN

A wide spectrum of PFAS precursors and arrowhead products may be present associated with AFFF use, storage and losses to the environment at fire stations and fire training grounds. Reference should be made to the site profile for AFFF (CL:AIRE, 2026l).

Wood Environment and Infrastructure Solutions (2020) list the following PFAS associated with AFFF:

- PFSAs: C2 – C11;
- PFCAs: C4 – C14 and C18;
- Various perfluoroalkane sulfonyl fluoride substances (PASF) and derivatives including sulfonamides (e.g. FBSA, FOSA), sulfonamidoacetic acids (e.g. FOSAA, EtFOSAA) and sulfonamidoethanols (e.g. FOSE, EtFOSE); and
- Fluorotelomers: 22 substances including sulfonates, alcohols, betaines, etc.

The actual PFAS present at any one site will be variable dependent on the AFFF formulations used, which will have varied over time. While some generalities may be drawn associated with the dates of operation and use, and the date of phasing out of PFOS-based AFFF and the introduction of fluorotelomer chemistry, actual practice varied. Records of AFFF type and composition are also likely to be poor.

6. SOURCE POTENTIAL FOR FIRE-FIGHTING GROUNDS AND FIRE STATIONS

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2 on the next page.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Fire-fighting training grounds	5	5	25	Foam use directly on the ground and in pits where fire is staged for training. Large quantities of AFFF are used and released to the ground with high frequency.
Waste water system	3	5	15	Runoff of waste water from paved areas is collected by drains. The waste water runoff can contain PFAS if an uncontrolled release of PFAS containing material has occurred on a paved area. Oil water separators present in the waste water system are ineffective in retaining the PFAS substances.
Vehicle parking areas / garage for Foam Producing Vehicles	3	5	15	Accidental release from engines and other vehicles containing AFFF. Considered to be low quantity.
Vehicle washing area	2	5	10	Area where fire engines are washed and tanks rinsed. PFAS containing materials can be released to the waste water or used in cleaning products.
AFFF Concentrate and bulk storage areas	5	1	5	May not be present at all fire stations with foam producing vehicles. Hub points may serve several fire stations. Current storage should comply with hazardous material storage regulations including bunding. Storage may have been less well managed in the past. Potential for release through accidental spillage and loss of containment. Release to ground likely to be of concentrate.
Vehicle fill points	5	1	5	May not be present at all fire stations where foam producing vehicles are based. Potential release during filling with spills to ground. Release to ground likely to be of concentrate.
Surface water drainage systems and tanks soakaways and effluent discharge points	1	3	3	Sediments likely to be contaminated by PFAS and to slowly release PFAS to the water environment.
Concrete or other semi porous hardstanding areas where PFAS have been used	1	2	2	Past adsorption of PFAS to concrete or other surfaces. Slow release of PFAS from concrete during rainfall events can potentially impact surface water and groundwater.

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This bulletin should be cited as follows: CL:AIRE, 2026. Fire-Fighting Grounds and Fire Stations. PFAS Site Profile 03. CL:AIRE, UK.

IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing. This profile focuses on Landfills.

Landfills

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment. The original landfill profile was prepared by Jacobs in 2022 and additional material was added by the Environment Agency in 2025.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern, and Defra (2024) for an investigation of PFAS in landfill leachate.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;

- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO LANDFILLS

Landfills are potential receivers of PFAS-containing waste materials from domestic, commercial and industrial sources. This site profile focuses on landfills accepting non-hazardous municipal solid wastes (MSW) and the potential type of PFAS encountered at this type of site.

The composition and make up of wastes have changed significantly over the last 70 years. In the mid-20th century it was common practice to burn household waste producing large quantities of ash. With the introduction of greater use of chemicals and plastics in the latter half of the century the composition of waste changed. Shifts in government policies aimed at adopting greater reliance on recycling and later the drive towards a circular economy has again changed the composition of the wastes disposed of in landfills. Landfill design and engineering have also developed over time with engineered systems being introduced during the late 20th century. As a result, the risk posed by landfills varies greatly between sites, each need to be considered individually when assessing and managing the risks.

3. CASE STUDIES

Numerous studies from around the world have been undertaken to measure and assess landfill leachate, including MSW landfills, construction and demolition landfills and landfills which have received industrial waste (Lang et al., 2017); (Gallen et al., 2017); (Gallen et al., 2016); (Knutsen et al., 2019); (Fuertes et al., 2017); (Busch et al., 2010). These studies have demonstrated the ubiquitous presence of PFAS in landfill leachates. A summary of the key findings from these studies is presented below:

- A study by Lang et al. (2017) measured the concentration of 70 PFAS in 95 samples of leachates from US landfills containing waste of different ages and in varying climates. The emphasis of the sampling strategy was to collect raw leachate as it leaves the landfill for offsite treatment at a Waste Water Treatment Plant (WWTP). All leachates contained PFAS compounds, with PFHxA, PFHpA, PFOA and PFHxS detected in all samples. The highest individual PFAS concentration was of 5:3 FTCA, with the mean 5:3 FTCA concentration at least three times higher than PFOA and PFOS combined. Younger waste was found to have higher concentrations of PFNA, 8:2 FTCA, 5:3FTCA and PFBS, which was thought could either be due to reduction in concentrations over time or changes in the types of PFAS used in products, for example PFBS and PFNA used as alternatives to PFOS and PFOA.
- A similar study was undertaken in Australia of measurements of nine PFAS (PFCAs and PFSAs) in leachate from 27 landfills (Gallen et al., 2017). The findings suggested PFHxA was the predominant PFAS, and mean PFAS concentrations were higher in leachate in current operational municipal landfills compared to closed ones. It was also reported that landfills accepting primarily construction and demolition wastes produced leachate that had higher mean PFAS concentrations than municipal landfills. Gallen et al. (2017) concluded that the contribution of leachate to the total load of PFAS entering WWTPs in Australia is minor compared to domestic waste water sources.
- Knutsen et al. (2019) investigated the presence of four short-chain PFAS and twenty-four long-chain PFAS in leachate and sediment from ten Norwegian landfills, receiving primarily MSW and in some cases industrial waste, contaminated soil and sewage sludge. Sampling of leachate was conducted as close as possible to where the leachate left the landfill and included both raw leachate and raw leachate diluted with storm water or groundwater. PFAS were ubiquitous, being detected in all landfill leachate samples. There was a

substantial variation in leachate concentrations observed between landfills, with the total sum of 28 PFAS per landfill ranging from 320–11,000 ng/l. PFBS and PFOS were the most abundant short chain and long chain PFAS measured respectively. Knutsen concluded that the relatively high abundance of short chain PFAS, particularly PFBS, in leachate demonstrates that considerable amounts of PFBS (and PFBS precursor) containing waste have been disposed of in Norwegian landfills. In addition, the presence of PFOS in leachate indicates that the phase-out in new commercial products had not reduced their concentrations in leachate entirely, due to both the presence in waste being currently deposited at the landfills, and the lag-time of leaching from waste previously landfilled (Knutsen et al., 2019).

- Fuertes et al. (2017) assessed PFAS in leachates from four municipal solid waste landfill sites located across northern Spain. Data were collected on the occurrence and concentration of eleven perfluoroalkyl carboxylates (PFCAs) and five perfluoroalkyl sulfonates (PFSAs). Total PFASs in raw leachates had a maximum concentration of 1378.9 ng/l, while PFAS in treated samples were twice as high, with total PFAS concentrations up to 3162.3 ng/l. PFCAs accounted for the majority of the detected PFAS, with perfluorooctanoic acid (PFOA) the dominant compound in raw leachates (42.6%), followed by shorter chain PFHxA (30.1%), PFPeA and PFBA. It was concluded that the overall increase of the PFAS content as well as the change in the PFAS profile after leachate treatment, could be explained by the possible degradation of PFAS precursors such as fluorotelomer alcohols or fluorotelomer sulfonates (Fuertes et al., 2017).
- A study in Germany sampled and analysed untreated and treated leachate from 22 landfill sites for 43 polyfluoroalkyl compounds (Busch et al., 2010). The dominating compounds in untreated leachate were PFBA (mean contribution 27%) and PFBS (24%). The following were also present at more than 1% of the sum polyfluoroalkyl compounds concentration; PFHxA (15%), PFOA (12%), PFPeA (6.0%), PFHpA (4.0%), 6:2 FTS (3.7%), PFOS (2.7%) and PFHxS (2.3%).
- Harrad et al. (2019) collected leachate samples from 40 landfills across the Republic of Ireland. These samples were tested for PFAS including PFBS, PFHxS, PFOS, PFOA, PFNA and various perfluorinated sulfonamides. PFOA and PFNA were detected in all samples, and PFBS, PFHXS and PFOS were detected in at least 80% of samples. The highest overall concentrations were observed of PFBS. Higher overall concentrations of PFAS were detected in landfills which had operated more recently and were lined. It was concluded the higher concentrations in lined landfills are likely related to the fact that lined landfills are found to retain organic matter leading to a higher organic content of leachate from such landfills (Harrad et al., 2019).

The various studies from around the world have indicated that PFAS are routinely detected in landfill leachate due to consumer products and other waste streams containing PFAS which have been disposed to landfill. Short chain (C4 – C7) PFCAs, such as PFBS, are commonly more abundant than longer-chain ones. This was suggested by some of the studies to be due to the possible degradation and/or biotransformation of PFAS precursors such as fluorotelomer alcohols or fluorotelomer sulfonates. The fate and transformation of PFAS inside landfills are complex, affected by combinations of external (e.g. climate, waste input) and internal (e.g. biodegradation, sorption) factors (Hamid et al., 2018).

3.1 Environment Agency Landfill Sampling

The Department for Environment Food and Rural Affairs (Defra) and the Environment Agency are currently evaluating the sources and extent of PFAS and other Persistent Organic Pollutant (POP) contamination in landfills in England. To date, this programme of work has consisted of a number of phases:

Defra (2019 – 2022) Landfill Leachate Survey:

- Phase 1 - included a literature review, confirmation of site selection for a survey of landfill leachate and analytical method development and optimisation (Defra, 2019).
- Phase 2 - included the site selection, sampling methodology, collection, and analysis of raw and treated landfill leachates samples from 17 permitted operational and closed landfill sites accepting predominantly MSW (Defra, 2024).

Environment Agency (2020-2022) PFAS Risk Screening Project:

- Phase 3 - included the site selection, sample collection, and analysis of raw and treated landfill leachates samples from 10 permitted operational and closed non-hazardous and 15 non-permitted historic non-hazardous landfill sites accepting predominantly MSW.

The objectives of the studies mentioned above were:

- to build an overall picture of chemical substances present in landfill leachates that are known to be, or suspected to be, harmful to the environment;
- to explore their potential removal during on-site leachate treatment processes; and
- to provide initial data on potential exposure pathways that may arise from discharge of raw and treated leachates into the environment.

Raw and treated leachate samples were analysed for 17 PFAS, namely, PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFPS, PFHxS, PFHpS, PFOS, 5:3 FTCA, 6:2 FTS, 8:2 FTOH, Gen-X (HFPO-DA) F-53B, PFECHS and sum of PFAS. Specific sampling methodologies were adopted to avoid cross contamination. A summary of the main findings is provided below and provides a snapshot of targeted PFAS identified in landfill leachates in England:

- Five compounds account for about 85 to 90 per cent of the total PFAS measured and there is a consistent order of prevalence, namely: **PFBS > 5:3 FTCA > PFHxA > PFOA ≈ PFBA**.
- PFAS concentrations in leachates show a strong correlation with two leachate strength indicators, namely ammoniacal-nitrogen (NH_3-N) and Chemical Oxygen Demand (COD). This suggests they are released during the biodegradation of degradable organic materials, and this is consistent with other studies (Gallen, 2017; Harrad et al., 2019).

- The PFAS data are left censored and right skewed, due to frequent non-detects and outliers within the dataset. This makes statistical analysis and data presentation more challenging.
- The highest individual concentrations recorded were PFBS (maximum 87.10 µg/l), PFBA (maximum 32.50 µg/l) and PFOA (maximum 26.90 µg/l).
- Raw leachate and treated leachates generally contain the highest sums of PFAS. Raw leachates generally contain higher proportions of PFBS, PFBA, PFPA, PFHpA, PFOA, PFHxS and 5:3 FTCA whereas treated leachates generally containing smaller proportions of 5:3 FTCA.
- There was a high percentage removal of 5:3 FTCA during aerobic biological treatment (SBR), averaging 98.2% at fourteen facilities (range 98.0% to 99.9%). There was also some removal or more likely biotransformation of other fluorotelomers during aerobic biological treatment (SBR).
- Downgradient groundwater samples typically contain greater sums of PFAS than upgradient groundwater samples. Downgradient groundwater samples typically detect similar PFAS as observed in leachate samples. Exceptions to this may be a sign of other sources or that other PFAS are leaching from elsewhere within the landfill.
- Landfills whose infill dates are post-Landfill Directive (2001) generally have higher percentages of PFBS in treated leachates, with PFBS being the dominant PFAS in most cases. The post-Landfill Directive treated leachates generally contain similar percentages of a number of PFAS and generally have similar substances detected. Landfills whose infill dates are pre-Landfill Directive have more variation in the proportions of PFAS detected in treated leachates. Similar patterns are observed when looking at the landfill status. This is potentially due to the general likelihood of operational landfills to be pre/post- or post-Landfill Directive and closed landfills to be pre-Landfill Directive.
- Raw leachates are more varied in the proportions of PFAS than treated leachates. PFBS is generally dominant in pre/post- and post-Landfill Directive sites. 5:3 FTCA, which was not detected in many of the treated leachates is well represented in the raw leachate samples. Similar to the treated leachates the raw leachates from pre-Landfill Directive sites tend to be more variable in terms of PFAS proportions and types. 5:3 FTCA is also not well represented in the groundwater samples.
- The PFAS detected are more variable between downgradient groundwater samples in pre- and pre/post-Landfill Directive sites. Generally, fewer varieties are detected in pre-Directive landfills, with PFOA and PFBS being relatively common. Pre/post-Directive sites generally detect higher percentages of PFPA, PFBS and PFOS.

The landfill type and waste categories are not varied enough to be able to draw any meaningful conclusions from at this stage. Further refining of the waste types and more sampling from hazardous sites, as well as more information about any leachate control measures at each landfill would allow further statistics to be run.

3.2 English Landfill Considerations

A review of landfill types within England was completed during PFAS Phase 2. The review identified two main groups of landfill types in England, permitted post-Landfill Directive, (i) engineered non-hazardous and hazardous, and (ii) historic non-engineered landfill, and PFAS risk evaluation was completed based on the landfill dataset downloaded from the Defra Data Services Platform.

PFAS presence in landfills can be related to type and date of waste input. Co-disposal landfills with waste input dates that range from pre-1976 to end of 2001 and which were licensed to accept household, commercial, industrial (now classified as non-hazardous wastes) and special (now hazardous) wastes. These waste types included liquid wastes commonly co-disposed with solid wastes. It is more likely that these earlier landfills will have received wastes containing PFAS. Other landfill types permitted to receive waste categorised as non-biodegradable wastes and inert wastes are considered less likely to have received PFAS containing waste.

Based on information obtained from the Defra Data Service analysed in PFAS Phase 2 some consideration has been given based on input dates, type of waste, and the presence of leachate control. Historical landfills with a last-recorded input date after 1960 and with no leachate control have a higher likelihood of having received PFAS-containing waste. Historical landfills with a date of last input of waste pre-1960 were excluded on the basis that PFAS were unlikely to have been used in England at that time. Landfills receiving inert waste only were also considered less likely to have PFAS-containing waste.

4. PROCESS

PFAS may be present in a wide range of waste streams disposed of to landfill including consumer products and domestic waste, manufacturing and packaging waste, and building and construction waste. The fate and transformation of PFAS inside landfills are complex, affected by combinations of external (e.g. climate, waste input) and internal (e.g. biodegradation, sorption) factors. Release of most of the PFAS from waste to leachate is thought to occur as a result of biodegradation, closely associated with onset of the methanogenic phase (Defra, 2024). The methane yielding stage also results in higher pH (>7) of leachate which appears to correlate with greater mobility of PFAS (Hamid et al., 2018). Leachate containing PFAS can either be directly discharged to ground (from older landfills without engineering containment measures, which was common practice in the 1970s and 1980s in the UK), or be collected for treatment in engineered/contained modern landfills.

5. KEY PFAS CONTAMINANTS OF CONCERN

Many types of PFAS may be present in UK landfills. The type of PFAS present in municipal waste is likely to include short chain PFAS such as PFBS, as well as long chain PFOS and PFOA, which are no longer registered for use in new products, but will continue to be present in household articles. For example, carpets and furniture treated with PFOS containing stain protection when manufactured in the 1980s or 1990s, being disposed of to landfills in later decades.

Table 1. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Historic non-engineered landfill, co-disposal sites accepting non-hazardous and hazardous wastes	5	5	25	Dilution and dispersal through sidewalls and base. Likely to be present in downgradient groundwater.
Post-Landfill Directive engineered non-hazardous and hazardous landfill accepting predominantly MSW	5	5	25	Leachate collection system; off-site tankering of waste leachate; effluent from on-site treatment plants. Many of the leachate treatment systems currently available do not effectively remove PFAS, therefore some discharges can still contain PFAS after treatment and its release may contribute to surface water and groundwater contamination (via onward release from Waste Water Treatment Works).
Post-Landfill Directive inert landfill	5	1	5	Pre-Landfill Directive inert waste landfills containing construction and demolition waste can contain PFAS. These types of landfills do not produce significant quantities of leachate as the material disposed cannot be biologically or chemically reactive to meet the requirements of inert waste. Therefore, inert landfills rarely have active leachate management systems. Modern post-Landfill Directive inert landfills are required to have an engineered barrier on the base and sides of the landfill which is of a suitable standard to prevent migration of contaminants. As such the potential release of PFAS to the environment from inert landfills is considered to be significantly less than hazardous and non-hazardous landfills.

The Environment Agency landfill sampling study detected a wide range of PFAS, including PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFPS, PFHxS, PFHpS, PFOS, 5:3 FTCA, 6:2 FTS, 8:2 FTOH, Gen-X (HFPO-DA,) F-53B and PFECHS. Raw leachate and treated leachates generally contain the highest sums of PFAS. Raw leachates generally contain higher proportions of PFBS, PFBA, PFPA, PFHpA, PFOA, PFHxS and 5:3 FTCA whereas treated leachates generally contain smaller proportions of 5:3 FTCA.

Based on the available literature, it is evident that it is not currently possible to predict the likely PFAS present based on the landfill age or type. The fate and transformation of PFAS inside landfills are complex and are controlled by a wide range of factors (e.g. climate, waste input, biodegradation, sorption) which means there is considerable variability between individual landfills.

6. SOURCE POTENTIAL FOR LANDFILLS

Following the methodology set out in section 1.3, a theoretical source potential has been developed for each site profile zone and is detailed in Table 1.

ACKNOWLEDGEMENTS AND SUGGESTED CITATION

The Landfill PFAS Site Profile was originally prepared by Jacobs for the Environment Agency PFAS Risk Screening Project in 2022. Additional material relevant to English landfills was added by the Environment Agency in 2025. The profile has been edited for publication by CL:AIRE. The Jacobs authors were Jane Thrasher, Francesca Giacomello, Hugh Masters-Williams and Yolande Macklin.

This bulletin should be cited as follows: CL:AIRE, 2026. Landfills. PFAS Site Profile 04. CL:AIRE, UK.

IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

PFAS Site Profile

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Metal Manufacturing and Finishing.

Metal Manufacturing and Finishing

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO METAL MANUFACTURING AND FINISHING

This site profile refers to sites where both ferrous and non-ferrous metals are manufactured, finished, or surface treatments are applied. The uses of PFAS at industrial sites can generally be divided into direct uses associated with manufacturing processes (e.g. application of PFAS treatments), and indirect uses associated with the application of fire suppression systems and fire-fighting foams containing PFAS. The metal sector covers a very wide range of site types and activities, many of which do not involve the use of PFAS. There are however some very specialist uses of PFAS in metal manufacturing and finishing processes which have the potential to impact the wider environment, and they are the primary subject of this site profile.

This site profile has been developed based on desk studies only and this has not included any interviews or assessments of any specific UK sites.

2.1 Regulation of Metal Manufacturing and Finishing Sites in England

The regulation of the metals sector in England is complex, and some facilities which may be using PFAS may not be currently regulated, or may be being regulated based on different activities.

Depending on the scale and nature of activities and materials used, some sites may be regulated under Control of Major Accidents and Hazards Regulations (COMAH) which may be required to have fire prevention measures in place, which can include fire-fighting facilities on the site. Further details are described in the site profile for COMAH Regulated Sites (CL:AIRE, 2026b).

Metal manufacturing and finishing sites may also be regulated under the Environmental Permitting Regulations (EPR) 2016, as Part A(1) sites, Part A(2) sites and Part B sites. The application of these regulations is complex, and depending on the process involved, they can be regulated under different industrial sectors such as the inorganic chemical sector, as defined in EPR Schedule 1 Part II Section 4.2 Part A(1)(f) - Inorganic Chemical Sector (EPR, 2016).

The regulation of activities involving 'production and processing of metals' is detailed in EPR Schedule 1 Part II Chapter 2. Many sites with specialist PFAS uses will be regulated under the 'surface treating metals and plastics' sector, as defined in EPR Schedule 1 Part II Section 2.3. These may be permitted as:

- Part A(1) activities, regulated by the Environment Agency, include surface treating metals and plastic materials using an electrolytic or chemical process where the aggregated volume of the treatment vats is more than 30 m^3, but exclude activities defined as Part A(2) sites;
- Part A(2) activities, regulated by the Local Authority, also include surface treating metals and plastic materials using an electrolytic or chemical process where the aggregated volume of the treatment vats is more than 30 m^3 but where, on the same installation, other activities are undertaken as defined within EPR 2016; these activities comprise Part A(2) and Part (B) activities listed elsewhere under Section 2.1 (Ferrous metals), Section 2.2 (Non-ferrous metals) and Section 6.4 (Coating activities, printing and textile treatments);
- Part B activities, regulated by the Local Authority, include any process for the surface treatment of metal which is likely to result in the release into air of any acid-forming oxide of nitrogen and which does not fall within Part A(1) or Part A(2) of this Section; these will include small volume platers who have processes including nitric acid treatments.

This means that facilities with activities that meet the Part A(1) activities for regulation by the Environment Agency (generally expected to be higher risk activities) may actually be regulated under Part A(2) because of the co-location of other activities at the installation. Facilities which fall below the size threshold may be

regulated by the Environment Agency as Part A(1) under the chemicals sector due to the use of certain chemicals, or because of other ancillary A(1) processes such as effluent treatment plant which can also trigger Environment Agency regulation despite Part A(2)/B metals activities.

In practice in the UK, as well as the regulated metal manufacturing and finishing sites, there are believed to be many businesses (both large and small) offering metal finishing services which may be 'falling between the gaps' and operating without permits. Some of these sites may be operating with Trade Effluent Consents for effluent discharge to sewer, but others may be working without any consents at all.

2.2 PFAS Use Associated with Fire Suppression Systems and Fire-fighting Foams

Large manufacturing facilities including iron and steel manufacturing sites where dangerous substances are present, are likely to be regulated as COMAH sites (refer to the site profile for COMAH regulated sites (CL:AIRE, 2026b). These sites are required to have fire prevention measures in place, which can include fire-fighting facilities on the site. This may include fire station and fire training areas, where AFFF will have been stored and used (refer to the site profile for AFFF (CL:AIRE, 2026l)). Fire prevention and protection systems in large manufacturing facilities are likely to include installed fire suppression systems which may include automated sprinklers (refer to the site profile for Fire Suppression Systems (CL:AIRE, 2026m)). These may include foam systems, particularly where the fire hazard is related to flammable or combustible liquids. AFFF concentrate containing PFAS is stored in tanks and released through sprinklers in response to a fire. Systems need regular testing and maintenance. While current methodologies may have been developed to enable testing without release of PFAS, this is less likely to have been the case in the past. Accidental release may also occur, either through system failure or false alarm.

Upper Tier COMAH sites have a requirement for regular live training of emergency procedures, which may include demonstration of fire-fighting capability including foam. While such exercises are now likely to be undertaken using PFAS-free training foam, this is unlikely to have been the case in the past. Residual PFAS may also be present following emergency response to incidents.

Other large manufacturing sites with a long industrial history may also previously have had their own on-site fire services even if not regulated under COMAH or similar predecessor regulations.

2.3 PFAS Use Associated with Metal Manufacturing and Finishing Processes

The properties of PFAS that make them particularly useful in the metal sector include thermal and chemical stability, and surfactant properties, for example, to lower the surface tension of electrolyte solutions. Metal finishing such as electroplating, anodising, coating (phosphating, chromating, and colouring), chemical etching and milling may use PFAS (US EPA, 2021).

PFAS also have applications as specialist coatings in the metal industry. Polymeric poly-fluoroalkyl or fluoropolymers, for example PTFE are used in dip coating, aqueous dispersion and powder coatings for surface treatment of metals (STM). These coatings can be applied in the form of paint or coating at the metal manufacturing site or at the point of use. Anionic PFAS may be combined with the polymeric PFAS to aid in the application, and may also be present as residues in the finished product.

According to Glüge et al. (2020), the uses of PFAS within the metal sector can be categorised in two main branches: metal plating and the manufacturing of metal products.

PFAS used in metal plating, electroplating, for chrome and other metals such as nickel, copper, tin and zinc may have the following functions:

- Preventing the evaporation of chromium (VI) vapour (mist suppressant) with the property of lowering the surface tension of the electrolyte solution. PFAS are very stable in strongly acidic and oxidising conditions (see section 2.4);
- Lowering the surface tension acting as non-foaming surfactant and increasing the strength of the nickel electroplate by eliminating pinholes, cracks, and peeling;
- Preventing haze by regulating foam (mist suppressant) and improving stability and help to produce a plate of uniform thickness; and
- In zinc and steel finishing, cationic and amphoteric fluorinated surfactants impart a positive charge to fluoropolymer particles which facilitates the electroplating of the fluoropolymer.

Other PFAS uses in the finishing of metal products have the following functions:

- Promoting the flow of metal coatings, to prevent cracks in the coating during drying;
- Acting as a corrosion inhibitor on steel;
- Improving the efficient life of alkali baths;
- Fluoride-containing phosphating solutions help to dissolve the oxide layer of aluminium;
- Cleaning of metal surfaces, dispersing scum, speeding the runoff of acid when metal is removed from the bath, and increasing the bath life;
- Promote water removal from processed parts; and
- In electroless plating of copper, PFAS can be used to disperse pitch fluoride in the plating solution.

The composition and formulations of PFAS used in fluorosurfactants for these diverse applications are not clear. While Glüge et al. (2020) provide a long list of potential applications, they provide only limited information on product formulations. Exact formulations are generally protected by commercial sensitivity and Material Safety Data Sheets (MSDS) provide only generic information such as 'fluorinated surfactants'. Furthermore, the manufacturers typically maintain a product trade name but develop the formulation over time including in response to increasing environmental concerns.

One fluorosurfactant that has applications in surface coating is 3M Novec fluorosurfactant FC-4432 (3M, n.d.). Product information available on 3M website (3M, 2009) details its use in surface finishing, but does not provide compositional information. A product information sheet dated 2003 (3M, 2003) states "Novec FC-4432 fluorosurfactant is the first in a new line of fluorochemical surfactants from 3M based on perfluorobutane sulfonate (PFBS). PFBS refers collectively to perfluorobutane sulfonyl compounds including perfluorobutane sulfonates". In 2022, 3M announced it would exit PFAS manufacturing and work to discontinue the use of PFAS across its product portfolio by the end of 2025 (3M, 2022). This is just one example of fluorosurfactants being marketed for surface treatment applications, there are many other producers and suppliers in the UK and worldwide.

The use of polymeric PFAS in specialist coatings has been identified as an additional potential use of PFAS in the metal industry. These coatings can be applied in the form of a paint or coating at the point of use, or also at the manufacturing site. Anionic PFAS may be combined with the polymeric PFAS to aid in the application, and may also be present as residues in the finished product.

PFAS used by metal finishing facilities may be transferred to waste water streams generated by the facility and ultimately discharged to surface waters or WWTW. Based on studies conducted by the US EPA since 2007 (US EPA, 2021), chromium electroplating and chromium anodising operations (collectively referred to as "chromium electroplating facilities") were identified as the most significant source of PFAS, particularly PFOS, in the metal finishing point source category.

2.4 PFAS Use Specifically Associated with Chrome Plating

Historically, the metal plating industry has used, and continues to use PFAS in some metal plating applications. Chromium electroplating is the electrochemical deposition of chromium from aqueous electrolytes onto surfaces. There are two broad types of chrome plating:

- Hard chrome plating which is mainly used where hard-wearing, abrasion and corrosion resistant surfaces are required, such as hydraulic systems; and
- Decorative chrome plating to produce an optically attractive surface finish combining high hardness, chemical resistance and toxicological safety, for example sanitary fittings.

The process involves passing an electric current between two electrodes which are immersed in an electrolyte bath comprising chromic acid. During this process aerosols of chromic acid are released. This can lead to workers being exposed to releases of chromium (VI), sulfuric acid and chromo-sulfuric acid (German Environment Agency, 2017). The addition of polyfluorinated surfactants (such as PFOS) to the chromic acid both lowers the surface tension of the bath by forming a thin, foamy layer on the surface, thereby acting as a mist suppressant. PFOS began being used in mist suppressants in the 1980s to reduce worker exposure to toxic chromium (VI) ions. PFOS-based mist suppressants have also been used in the past during plastic etching, where chromic acid is used to prepare the surface of plastics for metallic electroplating.

The chromium electroplating industry had a special derogation from the EU Regulation on Persistent Organic Pollutants (EU, 2019/1021) which prohibits the use of PFOS and its derivatives, other than for "mist suppressants for non-decorative hard chrome (VI) plating in closed loop systems", due to its essential role in occupational health in this industry. The derogation applies until September 2025.

According to ECHA (2023), the restrictions on the use of PFOS have led to the substitution with 6:2 fluorotelomer sulfonate (6:2 FTS) in chrome plating processes. According to the German Environment Agency (UBA, 2022), a 2017 survey of chrome platers showed that only wetting agents containing 6:2 FTS were in use in functional chrome plating and plastic, while in decorative chrome plating, 6:2 FTS-containing (60%) as well as fluorine-free (40%) wetting agents were used. The use of fluorinated substances other than 6:2 FTS was not noted.

Improvements in technology associated with decorative chrome plating mean that chrome (III) can now be used rather than chrome (VI), rendering the use of PFOS or alternatives for mist suppression in this industry unnecessary. However, it is still required in hard chrome plating process. According to Posner (2020), the most common alternative in hard metal plating since 2016 is 6:2 FTS.

Literature indicates that the PFAS formulation with the trade name F-53B is used as an alternative to PFOS for chrome plating in China (Pan et al., 2018). F-53B is known to contain two PFAS: F-53B major, 6:2 chlorinated polyfluorinated ether sulfonate or 9Cl-PF3ONS; and F-53B minor, 8:2 chlorinated polyfluorinated ether sulfonate or 11Cl-PF3OUdS). The research by Pan et al. detected F-53B minor (9Cl-PF3ONS) at very low levels in surface water in the River Thames, suggesting that it may be in use in the UK. The Environment Agency (2020) stated that it was not known to be used in the UK at the time, but this may be because the volumes used fall below the REACH threshold (quantities below 1 tonne per year by individual companies).

In 2023, the Environment Agency published an environmental risk evaluation report for F-53B (Environment Agency, 2023), although there was no information about the actual quantities on the UK market (including from imported goods). It was recognised that F-53B could be being used as a replacement for PFOS, particularly within the chrome plating industry. For the purposes of this evaluation, the Environment Agency assumed that F-53B is used as a mist suppressant in chrome plating with a UK market volume of 0.5 tonnes/year (based on assumptions around the phaseout of PFOS).

As mentioned in the previous section, PFAS used by metal finishing facilities may be transferred to waste water streams generated by the facility and ultimately discharged to surface waters or WWTW. Based on studies conducted by the US EPA in 2007-2009, chromium electroplating and chromium anodising operations (collectively referred to as "chromium electroplating facilities") were identified as the most significant sources of PFAS, particularly PFOS, in the metal finishing point source category (US EPA, 2009). US EPA (2009) studied PFAS in waste water from eleven chrome plating sites in the USA and found varying PFAS substances, predominantly PFOS, PFBS, PFHxS and PFNA. PFCAs including PFOA were present but at much

lower concentrations. The 2009 study did not include fluorotelomers such as 6:2 FTS in the monitoring suite. The 2021 US EPA multi-industry study (US EPA, 2021), detailed in case studies below, provides a more up to-date view. Using available sampling data, the US EPA estimated the average waste water concentration of 6:2 FTS was more than 100 times greater than any other PFAS evaluated.

3. CASE STUDIES

Four case studies identified from literature review were reviewed with examples of PFAS contamination associated with metal manufacturing and finishing. The findings are listed in Table 1.

4. PROCESS

PFAS used in the manufacturing process may be lost to the ground and water environment through discharge in process waste water and through accidental loss. The German Environment Agency study (UBA, 2022) demonstrated that even with a state of the art closed loop system and effluent treatment for the closed loop process water, PFAS were still present in elevated concentrations in the final waste water discharge from the site. The nature of PFAS means that they readily adsorb to surfaces and are subsequently slowly desorbed, leading to continuous 'bleeding through' of PFAS long after their use within a facility. In the German example it was

Table 1. Case studies.

1. US EPA Multi-Industry Study – Metal Finishing Point Sources
This preliminary report (US EPA, 2021) summarises the manufacture, use, and discharge of PFAS from facilities in five industrial point source categories including metal finishing. The report presents the US EPA's estimates of the types and concentrations of PFAS, including legacy long-chain PFAS and replacement short-chain PFAS, present in waste water discharges from these facilities. The US EPA documented that PFAS are used by metal finishing facilities in the USA and chromium electroplating facilities were identified as the most significant source of PFAS in the sector. PFOS-based mist and fume suppressants were frequently used until 2015, when there was a regulatory requirement to phase out mist and fume suppressants containing more than 1 percent PFOS by weight. Chromium electroplating facilities were found to have adopted alternative technologies, including mist and fume suppressants containing fluorotelomer-based substances (e.g., 6:2 FTS) and chlorinated PFESAs (e.g., F-53B), to replace use of PFOS-based products. US EPA estimated that, at the time of the study, around half the chromium electroplating facilities in the USA were still applying some type of PFAS-based mist and fume suppressant. The study confirmed that the use of PFAS-based mist and fume suppressants may generate waste waters containing PFAS, and sampling and analysis demonstrated the presence of legacy long-chain PFAS and replacement PFAS in waste water discharges to surface water and WWTW. It was estimated the average waste water concentration of 6:2 FTS was more than 100 times greater than any other PFAS evaluated. Despite the phase out of PFOS-based mist and fume suppressants, it was noted that some chromium electroplating facilities still report detectable levels of PFOS in their waste water, although no detectable amounts of PFOS or its precursors were found in the mist and fume suppressants in use in the factory. The study found that no chromium electroplating facilities had PFAS effluent limitations or pretreatment standards in their waste water discharge permit and very few actually monitored for PFAS in discharges.
2. PFAS contamination in electroplating concrete floors
A case study of a site in Europe where the concrete floor in electroplating workshops was found to be impacted with PFAS contamination was presented at a conference (Held, 2021). Concrete up to 5 cm below the surface found to be impacted with up to 1.8 mg/kg PFOS, and leachable PFOS up to 75 µg/l. The contamination was predominantly PFOS with minor constituents of PFCAs and PFSAs. The contaminated concrete required special landfill disposal. It is not known if soil and groundwater were also impacted at this site (Held, 2021).
3. Study of PFOS Substitution in chrome plating, Germany
The German Environment Agency (UBA) published a detailed review of the use and substitution of PFOS in chrome plating (UBA, 2022). This includes an overview of the processes involved, substitutes currently in use (primarily 6:2 FTS) and the information available on the behaviour and toxicity of those substances. Detailed studies were undertaken of two facilities in which PFOS and 6:2 FTS were or are used, tracing the pathway of the 6:2 FTS from the point of use to the point of discharge. The most detailed study was undertaken at a plant which uses an automatic electroplating machine for nickel plating and decorative chromium plating of metal parts. The plant has a closed chromic acid circuit and is described as 'state of the art' where 6:2 FTS is used for mist suppression. PFOS was previously used at the site. Waste water from the closed system is collected separately and treated by ion exchange prior to mixing with other process water. The study found high concentrations of 6:2 FTS (910 µg/l) in the waste water, as well as PFOS (14 µg/l) which was interpreted as being related to residual 'bleeding through' from previous use of PFOS in the system. The ion exchange was effective at removing 6:2 FTS and PFOS. However, the waste water stream further down the process path was found to contain 6:2 FTS (61 µg/l) and PFOS (1.2 µg/l). It was deduced that the 6:2 FTS at this point was coming from adsorption and subsequent desorption of PFAS on to the plastic coated racks used to hold the articles being plated, both at the rack demetallisation stage and at the initial degreasing stage when new articles to be plated are placed on the racks. No transformation products of 6:2 FTS were detected in the process path within the factory, however they were detected in the effluent from the receiving municipal WWTW, together with reduced concentrations of 6:2 FTS. This study demonstrated that treatment of only the closed loop substream for PFAS was not sufficient to prevent waste water emissions of PFAS from the electroplating shop, and treatment of the whole waste water stream was necessary. It also demonstrates the continued 'bleeding through' of PFOS long after cessation of use. The UBA report also mentions that cases of groundwater contamination with 6:2 FTS caused by electroplating are known from North Rhine-Westphalia and Baden-Württemberg, but have not been published so far.

Table 1. Case studies (continued).

4. Former hard chromium plating site in Iggesund
A groundwater investigation was completed around a former hard chromium plating site in Iggesund, which is in the northern part of Sweden (Alnehem, 2016). The site was operational from the 1940s until 2009. The hard chromium plating activity was one of the registered exceptions where PFOS was still used. The substances analysed for were PFCAs: C4 – C14, C16 and C18, PFSAs: C4, C6, C8 and C10 and 6:2 FTS. No information is provided on PFAS formulations used in chrome plating at the site. Results from the water extraction analysis showed eight detected PFAS, with PFOS as the major contributor (72 - 9600 ng/l) with the sampling points located closest to the actual hard chromium plating having higher concentrations than the other samples. PFBS and PFHxS (which can be produced as an impurity during the production of PFOS) were also found in high concentrations. PFCAs in all samples were detected in lower concentrations. 6:2 FTS was found in a small number of samples with different characteristics to the majority of samples, but its presence was attributed to AFFF rather than chrome plating. Additional to the PFAS analysis, the groundwater was also measured for chromium since the hexavalent form is used in the chromic acid bath during hard chromium plating. Chromium was found in high concentrations in the same two samples that had the highest PFAS concentration. The report concluded that if the facilities are left to deteriorate, it will lead to continuous spreading of chromium and the highly water soluble PFAS downstream to the Iggesundsån river.

deduced that much of the PFAS in the final waste water was coming from adsorption to the plastic racks holding the articles being plated, as well as bleeding through of PFOS from previous use.

At sites with older systems and poorer housekeeping, potential pathways for PFAS loss include spills during manufacturing activities, chemical storage, filling and discharging of plating baths and other equipment, waste storage and disposal, process water discharge, wash water discharge, storm water discharge and runoff.

Even where PFAS are no longer used at the site (or where specific PFAS such as PFOS are no longer used), they may continue to be released in waste water and storm water due to the past adsorption and slow release from surfaces within the process system and facility. This includes semi-permeable surfaces such as concrete and other pavement, drainage infrastructure and ground. PFAS may be lost to ground and groundwater through soft ground, through cracks in hardstanding and through soakaways.

Even where facilities have processes in place for containment and treatment of contaminated process water, PFAS may be present in other waste water streams discharged from the site under consents or otherwise. Discharge consents in the UK are currently unlikely to have included PFOS or any other PFAS in the regulated substances.

In larger manufacturing sites with fire suppression systems, an on-site fire station and the need for test exercises, the use of fluorinated AFFF over the years is likely to have resulted in discharge to ground, adsorption to surfaces (including hardstanding and drainage systems), flushing of spent foam to soft ground, equipment washing, test discharge of extinguishers and other processes. Refer to the COMAH (CL:AIRE, 2026b), AFFF (CL:AIRE, 2026l) and Fire Suppression Systems (CL:AIRE, 2026m) site profiles for more details.

For sites which have been operational for chrome plating since before the restrictions on the use of PFOS, there is potential for residual release of PFOS associated with legacy use, including slow release of PFOS previously adsorbed onto equipment and infrastructure surfaces and porous media including concrete.

5. KEY PFAS CONTAMINANTS OF CONCERN

For metal sites in general, there is the potential for a wide range of processes to be currently active on the site, or to have been active in the past, where PFAS may be present, including at high concentrations in the industrial chemicals in use.

For the metal manufacturing sites regulated by the Environment Agency under Part A(1) of EPR 2016, many of these are large metal manufacturing sites which are also COMAH sites, where the major source of PFAS is likely to be AFFF use. The site profile for AFFF (CL:AIRE, 2026l) should be referred to for information on key PFAS of concern for this use.

For chrome plating sites, historically PFOS was the predominant PFAS used in fume and mist suppressant, although the formulations are likely to have contained other PFAS present as impurities from the ECF manufacturing process (refer to the site profile for AFFF for further detail (CL:AIRE, 2026l)).

The Stockholm Convention includes a derogation to the use of PFOS as a mist suppressant in closed loop systems in hard chrome plating until September 2025. Indications are that the majority of users have already transitioned to formulations that do not contain PFOS. However, it is noted that PFOS continues to be detected in the waste water of plants where PFOS was used, many years after the end of PFOS use, due to desorption processes from all surfaces that once came into contact with PFOS.

6:2 Fluorotelomers appear to be the common replacement chemistry for chrome plating. Formulations based on 6:2 FTS appear to be in widespread use in Europe while F-53B (including 6:2 chlorinated polyfluorinated ether sulfonate (9Cl-PF3ONS) and 8:2 chlorinated polyfluorinated ether sulfonate (11Cl-PF3OUdS)) is also used in China. The 6:2 fluorotelomers have the potential to degrade to short chain PFCAs include PFHxA, and they are also relatively stable in the environment, and persist in waste water effluent, surface waters and groundwater. Where it has been included in the testing suite, 6:2 FTS is frequently the most abundant PFAS detected in groundwater and surface water in England.

PFAS also have wide application in other surface plating activities as well as chrome plating, where they are used as degreasers and surfactants. As detailed above, there is very limited information available regarding the composition of fluorinated surfactants currently in use, and used in the past. Formulations in past use are likely to have included PFOS and other long chain PFAS. Current formulations are likely to be based on short chain PFAS and precursors including 6:2 FTS and PFBS.

6. SOURCE POTENTIAL FOR METAL MANUFACTURING AND FINISHING

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Former fire-fighting training activities (large metal manufacturing sites regulated under COMAH)	5	5	25	See site profile for COMAH regulated sites for further details (CL:AIRE, 2026b). Foam use when testing systems and practising emergency response. Historically, foams were used directly on the ground and pits where fire was staged for training. Large quantities of AFFF were used and released to the ground with high frequency. Currently this practice is improved and runoff likely to be contained, therefore the high source potential is related to the old practice and can be reduced for more recent fire training activities. Potential for adsorption to infrastructure including hardstanding and drainage systems, and ongoing slow release.
Process water	5	3	15	Potential release of process effluent. On-site treatment or containment may not capture all pathways; may be discharged via discharge consent to sewer or to surface water.
Waste water system	3	5	15	May include process waste water and drainage water from working areas. On-site effluent treatment processes for general waste water unlikely to reduce PFAS content. May be tankered for off-site disposal to WWTW.
Concentrates storage area including AFFF storage	5	1	5	Leaks can occur and if good practices are not in place PFAS can reach the drains via runoff.
Decommissioning and demolition of redundant plant	5	1	5	Due to adsorption PFAS may be present in all process plant. It has been found that PFAS persist in plant for several years after cessation of use. There will therefore be a risk of it being released to the environment at the end of the plant's life during disposal.
Surface water drainage systems and tanks, soakaways and effluent discharge points	1	3	3	Sediments likely to be contaminated by PFAS and to slowly release PFAS to the water environment.
Concrete areas and other semi-permeable surfaces where PFAS have been used	1	2	2	Past adsorption of PFAS to concrete surfaces. Slow release of PFAS from concrete can potentially impact surface water and groundwater.

PFAS Site Profile

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

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PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

CL:AIRE

PFAS SP 06
(July 2026)

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Military Bases (other than Air Transport Sites).

Military Bases (other than Air Transport Sites)

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO MILITARY BASES (OTHER THAN AIR TRANSPORT SITES)

This site profile covers military bases other than military air transport sites which are included in the site profile for Civil and Military Airfields and Airports (CL:AIRE, 2026a).

The use and release of AFFF at military bases is documented for US military sites (ESTCP, 2017) and also by the Australian Government Department of Defence. At the time of writing, the Australian Government Department of Defence is undertaking a national program to review, investigate, and implement a comprehensive approach to manage the impacts of PFAS on, and in the vicinity of, some of its bases around Australia (Australian Government Department of Defence, 2022). Data for military bases in England are not currently available at the time of writing.

Based on the studies from the USA and Australia, military installations including army and navy bases and barracks, may include areas that are at risk from petroleum fires and accordingly AFFF has potentially been used and stored. The areas identified are:

- Firefighting training areas;
- Firefighting equipment test areas (e.g. training truck spray nozzle test areas) and areas where AFFF was released to the environment (repeated small releases or as a significant one-time release);
- Fire stations including equipment washdown;
- Current and historical AFFF storage areas;
- Storage and distribution of fuels (e.g. tank farms/fuel farms) likely to have foam suppression systems;
- Emergency response sites; and
- Former and active ranges for weapons firing, vehicle training and explosives testing.

In addition to the use and storage of AFFF, other PFAS containing materials, such as surfactants, additives, vapour suppression products, waxes and lubricants, may have been used in additional activities, including:

- Chromium plating shops;
- Teflon-coating shops;
- The use and storage of other substances potentially containing PFAS (such as speciality paints);
- Mechanic shops where heavy-duty vehicles and appliances are maintained and repaired and the use and storage of substances potentially containing PFAS (hydraulic fluids, waxes, greases, hydraulic fluid, specialty paint);
- Bilge and oily waste water (BOW) transferred from Navy vessels to collection barges and ultimately into the waste water treatment plant, can contain PFAS (e.g. bilge washing) (NESDI, 2021);
- Wash racks used to wash fire engines or where large amounts of waxes were used; and
- Areas where pesticides or herbicides containing fluorinated compounds are applied.

Chromium plating and Teflon-coating shops are frequently present on US military bases. It is currently unknown if these activities are also present on British military bases and, therefore, they have not been included in the risk evaluation table at the end of this profile.

Military ports also represent a potential source of PFAS, which is likely to be applied in the bilge washing process to remove oil residues. The waste water from the bilge washing process is likely to be disposed of via the port's waste water treatment plant. PFAS may also be present in bilgewater resulting from AFFF use on board ships.

On-site landfills and waste water treatment sludges and effluents can also be impacted by the use of PFAS containing material within the military bases.

PFAS Site Profile

Table 1. Case studies.

1. California Water Board PFAS Program – Military Sites
The California Water Board (2022) provides published information on PFAS investigations at military sites in California, including background information and details of sites known to be impacted by PFAS. Military installations in California started using AFFF in the 1970s as a firefighting agent to extinguish chemical fires or spills and also used during crash crew training exercises, hangar system operations and testing, and for other emergency response actions. The Department of Defense (DoD) also uses materials that can contain PFAS in the vapor suppression systems at plating shops. The California Water Board lists 13 army sites and 32 navy sites (as well as 18 air force sites) in California with known or suspected PFAS release.
2. Australian Government Department of Defence
The Australian Department of Defence (DoD) has a PFAS Investigation & Management Program, comprising a national program to proactively review, investigate and implement a comprehensive approach to manage the impacts of PFAS on and in the vicinity of its bases around Australia (Australian Government Department of Defence, 2022). In the interests of transparency, the DoD has made available results of site assessment and testing at their sites. Case studies have also been presented at technical conferences in the UK. Examples include the Bandiana Military Area and the Robertson Barracks which were investigated for PFAS. At the Bandiana Military Site, 15 potential sources of contamination were initially identified as locations where AFFF had either been used or disposed of. Results from the sampling programme suggested the main way that PFAS moved off-base was via surface water flow and several drains and creeks. At the Robertson Barracks, historical uses of AFFF were identified and periodic monitoring of groundwater, surface water and sediments was undertaken to assess changes in the distribution, concentration, and transport (pathways and flow rates) of the contaminants. The monitoring results indicate stable PFAS concentrations in groundwater in the vicinity of the base with fluctuating PFOS and PFHxS in cross gradient direction of the source. PFAS concentrations were also found in on-base drainage lines.

3. CASE STUDIES

Two case studies were reviewed with examples of PFAS contamination associated with military bases. The findings are listed in Table 1.

4. PROCESS

PFAS may enter rivers, streams, lakes and coastal waters in the form of water runoff, waste water discharge, and landfill leachate. PFAS impacted bilgewater is a particular consideration at naval sites. Oil water separators are a release point due to their inability to treat and stop PFAS being discharged. PFAS may also contaminate groundwater through leaching from sites where fire-fighting foams have been applied or where accidental spills of substances containing PFAS have occurred. Watercourses may also be impacted from migration of PFAS impacted groundwater providing baseflow.

5. KEY PFAS CONTAMINANTS OF CONCERN

All types of PFAS to be considered with the majority released via AFFF. Reference should be made to the site profile for AFFF (CL:AIRE, 2026l). Low quantities of PFAS may also be used in heavy-duty vehicle and appliance repair and maintenance, chrome plating where present and use of pesticides and herbicides.

6. SOURCE POTENTIAL FOR MILITARY BASES (OTHER THAN AIR TRANSPORT SITES)

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Fire-fighting training grounds	5	5	25	Foam use directly on the ground and pits where fire is staged for training. Large quantities of AFFF are used and released to the ground with high frequency.
Waste water system	3	5	15	Runoff of waste water from paved areas is collected by drains. The waste water runoff can contain PFAS if an uncontrolled release of PFAS containing material has occurred on a paved area. Oil water separators present in the waste water system are ineffective in retaining the PFAS substances.
Vehicle washing area	2	5	10	Area where fire engines are washed and tanks rinsed. PFAS containing materials can be released to the waste water or used in cleaning products.
Fire stations	2	3	6	Foam containing PFAS stored in tanks within fire stations, fire engines and pumps at vehicle fill points. Release to the environment may be via accidental spills. It is considered that low quantities of PFAS may be released at these locations. Current tanks may be provided with leak alarms and fire engines with sophisticated systems to avoid spills.

Table 2. Site Profile Zone Source Potential (continued).

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Tank farms/fuel farms	5	1	5	Fuel farms are likely to have foam fire suppression systems, with foam stored in tanks. Major releases may occur during an accident with minor releases from accidental spills from the tanks or during testing and maintenance.
Former and active fire ranges	5	1	5	AFFF may be used to extinguish accidental fires.
Bilge washing (Navy)	2	2	4	Substances containing PFAS may be used and the waste water is washed away via waste water treatment plant or discharge to surface water.
Mechanic shops	1	2	2	PFAS may be used where heavy-duty vehicles and appliances are maintained and repaired (fluids, waxes).
Areas where pesticides or herbicides are applied	1	1	1	PFAS contained in herbicides and pesticides and likely to be spread within the site as ground control routine. Accidental release of mixture containing PFAS may occur in the pesticides storage area. Considered to be low quantity.

ACKNOWLEDGEMENTS AND SUGGESTED CITATION

The PFAS Site Profiles were originally prepared by Jacobs for the Environment Agency PFAS Risk Screening Project (Phase 4) and have been edited for publication by CL:AIRE. The authors were Jane Thrasher, Francesca Giacomello, Hugh Masters-Williams, Yolande Macklin, Laura Richmond, Simon Tempest and Hannah Foster.

This bulletin should be cited as follows: CL:AIRE, 2026. Military Bases (other than Air Transport Sites). PFAS Site Profile 06. CL:AIRE, UK.

IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

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CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on the Oil and Gas Industry (onshore exploration and extraction operations).

Oil and Gas Industry (onshore exploration and extraction operations)

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);

- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO OIL AND GAS INDUSTRY (ONSHORE EXPLORATION AND EXTRACTION OPERATIONS)

The oil and gas industry can be divided into three sectors: upstream, midstream and downstream. This site profile relates to midstream and upstream activities. The downstream sectors are covered in the Refineries and Fuel Sites profile (CL:AIRE, 2026i).

An overview of where PFAS are applied in the oil and gas industry is given by Glüge et al. (2020) (supplement no.1) in 'An overview of the uses of per- and polyfluoroalkyl substances (PFAS)'. Hussain et al. (2022) also provide a useful overview on the breadth of potential applications for PFAS surfactants in oilfield activities, and current known applications. These uses are summarised below:

- Drilling process: PFAS in fluorinated surfactants can be used as hydrocarbon foaming agents in drilling fluids for several reasons:
  - ◊ the volume of liquid in a foamed fluid is smaller than in non-foamed fluids, thus, less fluid gets lost in permeable subterranean formations;
  - ◊ foams have lower densities than non-foamed drilling fluids, and the use of foams lowers potential formation damage when the pressure in the drilling fluid is lower than the pore pressure in the surrounding rock;
  - ◊ in the past, drilling fluids with long-chain perfluoroalkyl groups were used, for example, perfluoro-octane sulfonamide groups. However, there has been a trend moving away from using perfluorooctyl-based fluorinated surfactants.
- Chemical driven oil production: PFAS in fluorinated surfactants can be used in oil-well stimulation during water flooding and in non-aqueous stimulation fluids for foaming hydrocarbon liquids. Fluorinated surfactants can increase the effective permeability of the formation, and can be used to render the surfaces of the oil bearing reservoirs hydrophobic and oleophobic. Different fluorinated surfactants have been patented for these applications, depending on the type of the formation. Fluorinated surfactants can also be used in fracturing subterranean formations penetrated by a wellbore. Fluorinated surfactants have also been patented as foaming agents in liquid CO_2 fracturing fluid systems.
- Chemical driven gas production: PFAS in fluorinated surfactants can be used to change low-permeability sandstone gas reservoirs from strongly hydrophilic to weakly hydrophilic to make gas recovery easier.
- Oil and gas transport: pipes used in the production and transportation of oil are generally large and for reasons of economy are manufactured from carbon steel rather than more expensive corrosion resistant alloys. However, water, sulfur, sulfur dioxide, and carbon dioxide, present in the oil typically make the oil acidic causing corrosion of the interior surface of the pipe. Lining the interior surface of oil well pipes with fluorocarbons can prevent this corrosion. The presence of perfluoropolymer in the primer layer enables the overcoat to melt bond to the primer layer when they are heated. Lining the exterior of offshore pipes can protect them from corrosion from sea water. Fluorinated surfactants have also been patented to aid reducing the viscosity of crude oil for pumping from the borehole, as viscosity can limit the rate crude oil can be produced from a well.
- Oil and gas storage: evaporation of liquid fuels (e.g. gasoline) can be prevented by an aqueous surface film containing anionic surfactants. Evaporation losses can also be reduced by covering the liquid surface of petroleum storage tanks with a floating layer of cereal (e.g. corn, wheat, or perlite) treated with a fluorinated surfactant.

- Oil and gas containment: oil spills on water can be contained and prevented from spreading by a chemical barrier containing a fluorinated surfactant. It is also claimed that perlite or vermiculite, treated with a cationic fluorinated surfactant is hydrophobic and effective in cleaning oil spills.

The main concern of PFAS use at conventional and unconventional sites is its release into the environment via flowback fluids. Flowback fluids are defined as "fracturing fluids contaminated with minerals and naturally occurring radioactive material (NORM) returned to the surface during and following high volume hydraulic fracturing" (Environment Agency, 2013).

In the USA, disposal practices of exploration and production wastes have included downhole injection, land spreading and onsite burial as well as off-site landfilling and incineration (United States Environmental Protection Agency, 2019). However, regulatory controls in England require onsite treatment or onsite storage and subsequent offsite transfer to an Environment Agency approved waste treatment facility for disposal in accordance with the receiving waste treatment facility's environmental permits, which limits the potential for PFAS containing wastes to be introduced into the ground (Environment Agency, 2013).

There is limited understanding of PFAS use at conventional oil and gas exploration sites in the UK, as there is no information available on this. Evidence has been found for the potential use of fluoropolymer PFAS as drilling additives in the UK, but no evidence of the non-polymeric PFAS which are of particular environmental concern, but may potentially be used within the sector (as detailed by Hussain et al. (2022)).

It is possible that installations storing large quantities of flammable substances, such as tank farms, could be users of AFFF or fluoroprotein foam (FP) / film-forming fluoroprotein (FFFP) fire suppression systems, though there is no tangible evidence to confirm this. Fire Prevention Plans (FPPs) for oil and gas exploration sites are dealt with through the Health and Safety Executive and could not be supplied to inform this profile.

3. PROCESS

PFAS losses in the drilling process may contaminate groundwater. PFAS may also contaminate groundwater through leaching from sites where fire-fighting foams have been applied. In addition, PFAS may enter rivers, streams, lakes and coastal waters in the form of water runoff and waste water discharge.

4. KEY PFAS CONTAMINANTS OF CONCERN

There is the potential for a wide range of PFAS to be present, an indicative list is reported by Glüge et al. (2020) (supplementary data) and details of those associated with AFFF use can be found in the site profile for AFFF (CL:AIRE, 2026l). Hussain et al. (2022) also provide detail on the chemistry of a number of non-polymeric PFAS surfactants.

5. SOURCE POTENTIAL FOR THE OIL AND GAS INDUSTRY

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 1.

ACKNOWLEDGEMENTS AND SUGGESTED CITATION

The PFAS Site Profiles were originally prepared by Jacobs for the Environment Agency PFAS Risk Screening Project (Phase 4) and have been edited for publication by CL:AIRE. The authors were Jane Thrasher, Francesca Giacomello, Hugh Masters-Williams, Yolande Macklin, Laura Richmond, Simon Tempest and Hannah Foster.

This bulletin should be cited as follows: CL:AIRE, 2026. Oil and Gas Industry (onshore exploration and extraction operations). PFAS Site Profile 07. CL:AIRE, UK.

Table 1. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Process water from drilling	5	3	15	Potential release of process effluent. This will be discharged either to sewer or through a site discharge consent to surface water.
Fire Suppression System	3	3	9	Oil and gas storage may have fire prevention systems installed. Foam fire suppression systems may be a source of release during testing and maintenance, system failure, or accidental triggering. In the past, testing is likely to have required active release of foam. Foam released due to accidents or testing is likely to have been collected and discharged via the site drainage system. Even if foam suppression systems have been converted to PFOS-free or fluorine-free foams, there may still be carryover of PFAS from previous foams used.
Concentrates storage area including AFFF storage	5	1	5	Leaks can occur and if good practices are not in place PFAS can reach the drainage system or be released to ground via runoff.
Downhole applications	5	1	5	Release of PFAS underground during oil-well stimulation during water flooding. Impact considered unlikely to reach drinking water.

PFAS Site Profile

IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

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10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Paper and Cardboard Manufacturing.

Paper and Cardboard Manufacturing

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO PAPER AND CARDBOARD MANUFACTURING

This site profile covers the occurrence of PFAS related to the manufacturing of paper and cardboard. It does not cover the occurrence of PFAS in imported paper and cardboard materials manufactured outside of England, and their subsequent recycling or disposal.

PFAS from paper and cardboard are of particular interest because there have been some well publicised examples in Germany and the USA of widespread contamination of agricultural land related to paper manufacturing (detailed further in the case studies in section 3). These appear to be associated with PFAS-contaminated sludge from paper manufacturing having been used for land spreading as a soil conditioner.

Information from the Nordic Council of Ministers (NCM) (2017) states that PFAS have been used by the paper and cardboard manufacturing (PCM) industry since the 1950s. Approximately 20–25 different coatings are used by the PCM industry to coat paper and cardboard materials that come into contact with foods. One estimate suggested that 32 to 60 tonnes of PFAS were being used in the UK PCM sector per year in the early 2000s (RPA Ltd., 2004). Another estimate suggested that approximately 160 tonnes of PFOS-related compounds were used in the paper industry within the EU in 2000 (German Environment Agency, 2020). However, by 2010 production of paper using PFOA had reduced by 95%.

According to a position statement on perfluorinated compounds (PFCs) published by the UK Confederation of Paper Industries (CPI) in 2017: "The vast majority (99%+) of paper packaging manufactured in the UK, including by CPI Member Companies, does not use PFCs. In the small number of specialist applications where PFCs are used, UK manufacturers have ceased using PFOA and PFOS" (CPI, 2017). An updated position statement (CPI, 2023) states that "The vast majority (99%+) of paper and packaging manufactured by CPI Member Companies do not intentionally add PFAS substances" and that based on available evidence, state that "the sector is not likely to be a significant source of PFAS in the environment. UK mills look like being a much smaller potential source than reported in other literature".

2.1 Uses of PFAS

The properties of PFAS lend their use within the PCM industries as an oil, water and temperature repellent, or resistant coating. In addition, it is also used in printing inks and as a moisture barrier (Nordic Council of Ministers, 2017). It is estimated that up to 17% of foods are packaged in paper and cardboard, with food ingestion thought to be one of the main sources of human exposure to PFAS (Nordic Council of Ministers, 2017). ITRC (2023) note PFAS have been used as grease-proofing agents on food contact materials (FCM) to prevent oil, grease, and moisture from foods from leaking through the packaging. This includes coated paper and cardboard such as pizza boxes, microwavable popcorn bags, parchment paper, fast food wrappers, paper cups, pet food bags, and other items. Other applications of PFAS within PCM include surface coatings on non-food paper packaging, e.g. carbonless copy paper and masking paper.

With respect to FCM, there are two main types of barriers to grease, fats and liquids for paper and cardboard. Firstly, a physical barrier (e.g. plastic film and aluminium film lamination in the paper) and secondly a chemical barrier added to the paper/cardboard. A chemical barrier can be added to the pulp or as a surface treatment of the cardboard (Nordic Council of Ministers, 2017). 'Internal' chemical barriers within the pulp require greater amounts of the agent, which subsequently forms a barrier during the pressing and drying process. 'External' chemical barriers are added after production of the paper as a direct coating or mixed with varnish as a lacquer. In the 1970s the application process moved from an acidic pH process to an alkaline process due to paper degradation. There was also a move towards shorter chain PFAS. Approximately 1–1.5% fluorochemical (by weight of dry fibres) is needed for paper protection (Danish Ministry of the Environment, 2005), but 4% by weight can be used when mixed into the pulp (Nordic Council of Ministers, 2017).

PFAS Site Profile

A report by 3M (1999) provides a US view of the fluorochemical use in the PCM industry in the 1990s. The use of fluorochemicals in the products impart grease, oil and water resistance to paper and paperboard substrates. They are used for food contact applications (plates, food containers, bags and wraps) and non-food applications (folding cartons, containers and carbonless forms and masking papers). The 3M overview stated that the fluorochemicals can be applied to paper and paperboard during the manufacturing process or converting operation, as summarised below:

- Paper mills use fluorochemicals to treat paper fibres during the paper or paperboard manufacturing process. The application points for the fluorochemical at the paper mill can include wet end of the paper machine, size press, calendar stack or clay coating; and
- Converters, convert fluorochemically treated paper and/or paperboard into wraps, bags, cartons, etc., for desired end use.

The 3M overview notes that approximately 95% of the fluorochemicals used in the paper and packaging industry are applied during the papermaking process at the paper mill. It is estimated that 73% of the fluorochemicals used by US paper mills is applied via the size press (3M, 1999).

A general review on how PFAS were applied to the PCM process is presented by 3M (1999). The fluorochemical products arrive at the paper mill receiving dock and are stored in a designated area. For use in treating paper webs, the fluorochemicals are moved near the makedown area for pumping into a tank. In some cases, direct pumping of the fluorochemical to a size press operation occurs. The fluorochemical is typically applied in a 0.5 to 1% (fluorochemical w/ w) concentration in a starch/water solution. After the paper web is treated, the water is evaporated via numerous steam heated dryer cans and collected on a reel. The reel is then transported to a converting line, where the parent reel is slit down to a converting size roll for shipment to the converter. For wet end applications, the fluorochemical product is directly pumped to the pulp slurry prior to forming. Forming is the process of retaining fibres and draining water to form a usable article or web. Following forming, the manufacturing process includes pressing and drying, similar to that described above (molded articles do not go through the converting operation). During this process there is the potential loss of fluorochemicals to ground or drainage network and subsequent release to the water environment.

A 2004 report on PFOS by Risk and Policy Analysts Limited (RPA) (2004) provides some insight into information that may be available with regards to past use of PFAS (and specifically PFOS) in the paper manufacturing industry. They found that even though paper was reported as representing 15% of the UK PFOS market (prior to the withdrawal of PFOS by 3M), none of the trade associations contacted by RPA were able to identify UK applications of PFOS, or possible users. RPA (2004) also stated that it was believed that the majority of the PFOS related substances that were used were replaced by unspecified non-PFOS based fluorochemical alternatives, although applications may have been limited by the cost of the chemicals. Studies in the Netherlands indicated that much of the paper and board treatment actually took place outside the Netherlands, and the treated paper was subsequently imported, which may also be the case in the UK.

According to Glüge et al. (2020), side-chain fluorinated acrylate polymers derived from perfluoroalkane sulfonamide alcohols or fluorotelomer alcohols have become the most widely used polymers in FCM due to their good oil, grease, and water repellence. Additionally, perfluoropolyether-based phosphates and fluoropolymers have become widely used treatments for food contact paper and paper packaging. Glüge et al. (2020) also report that several PFAS have been detected in paper and packaging for food-contact articles.

Toilet paper has also been identified as a potential source of PFAS, particularly relevant to Waste Water Treatment Works. A recent study by Thompson et al. (2023) analysed samples of toilet paper from four world regions for 34 PFAS. All the samples contained detectable PFAS, with by far the largest single PFAS among those detected being 6:2 diPAP, representing 91% ±8% of the total mass of PFAS on average. The paper notes that PFAS are a known wetting agent used to increase the efficiency of the pulping process as well as being used elsewhere in paper production and that toilet paper is often manufactured from recycled paper fibres (which may themselves contain PFAS).

The UK CPI position statement (CPI, 2017) acknowledged that PFCs, which include specific variants such as PFOA (perfluorooctanoic acid) and PFOS (perfluorooctane sulfonate), have historically been used in a variety of industrial applications including liquid resistance in packaging. The position paper stated that the vast majority (99%+) of paper packaging manufactured by CPI Member Companies, does not use PFCs of any sort. There are some minority speciality applications, such as greaseproof papers and medical non-packaging, which do use PFCs. However, these are an extremely small percentage of total paper packaging or are not packaging (and will be destroyed at end of life) (CPI, 2017). The UK CPI updated position statement (CPI, 2023) confirmed that “the vast majority (99%+) of paper and packaging manufactured by CPI Member Companies do not intentionally add PFAS substances” and “there are a few minority speciality applications which use PFAS, where the PFAS provide either water or grease resistance which are needed for the products to deliver their technical requirements. Both companies involved are actively looking for replacement processes, but suitable alternatives are proving difficult to identify. However, it is worth noting that these two products are extremely unlikely to be present in recycling streams and so are unlikely to be a source of PFAS in recycled product or packaging”.

CPI (2023) also describes the findings of an Environment Agency funded sampling study at five UK sites. A total of 65 samples were taken from the paper representing a variety of operational scales, type of input paper, and geographic locations in England. The samples included input paper, crumb, input water, effluent, and output product samples in order to provide data on both the inputs and outputs of the processes. All 65 samples are reported to have had concentrations of PFAS well below 1 mg/kg. When identified above the limit of detection PFOS, PFOA and PFHxS were <0.001 mg/kg. Polyfluoroalkyl phosphate esters (PAPs) were identified in several samples but further work is required to quantify the concentrations. PFAS were detected at low concentrations in some of the input water samples and it is acknowledged that paper mills are a discharge point for a small amount of PFOS, PFOA and PFHxS. However, based on the sampling data, it was concluded that the PFOS, PFOA and PFHxS originated in the input water rather than

the recycled wastepaper stream and may be concentrated into effluent and crumb during the process. The key message concluded from this study by the CPI is that the UK paper and packaging sector appears unlikely to be a significant source of PFAS in the environment.

According to the CPI, the UK has 47 paper mills, with operations spread throughout England, Scotland, Wales and Northern Ireland. These mills produce around four million tonnes of product per year with almost a million tonnes exported, either directly or as packaging around UK manufactured goods.

The multi-industry analysis conducted by the United States Environmental Protection Agency (US EPA) (2021) gives an overview of PFAS uses in the USA for paper and cardboard. The research conducted by the US EPA stated that PFAS have been, and continue to be, used by pulp, paper, and paperboard facilities in the USA, however, only a small subset of facilities is actively applying PFAS and it appears the production of paper products containing PFAS at these facilities is a small percentage of the overall production. The use of PFOA and PFOS was phased out approximately 10 years prior to the time of reporting, but the industry continues to use approved short-chain PFAS in limited quantities in the manufacture of food contact packaging and specialty paper products. PFAS may be in additives mixed with the pulp prior to forming it into paper or in coatings applied to the surface of the paper after the paper is formed to enhance resistance to water, oil, and grease. The US EPA did not identify any pulp, paper, and paperboard facilities employing waste water treatment systems known to effectively reduce PFAS in industrial waste water. The USA paper industry reports that the application of PFAS to pulp, paper, and paperboard products is typically a dry or closed-loop process and may not generate a waste water stream, however, the US EPA documented that PFAS, including legacy long-chain PFAS and replacement PFAS, are present in waste water discharges from pulp, paper, and paperboard facilities to surface waters.

3. CASE STUDIES

Three case studies identified from a literature review are presented in Table 1 relating to PFAS and the PCM industry.

4. PROCESS

Two main processes are found using PFAS in the manufacturing of paper:

- cardboard mixed with the pulp as additives before it is formed into paper; and
- coatings containing PFAS applied to the finished paper.

According to the multi-industry analysis conducted by US EPA (2021), where coatings containing PFAS are applied to the paper, a closed-loop, recirculating system is used and excess coating is captured and reused.

In the process where PFAS treated paper is made starting from the pulp, PFAS contaminated process water can be generated and discharged.

In both processes, PFAS concentrates may be stored and handled at the paper mill or paper treatment manufacturing facility.

Table 1. Case studies.

1. Paper product production identified as the main source of PFAS in a Norwegian lake
Research conducted by Langberg et al. (2021) in 2015 on Lake Tyrifjorden in Norway found elevated PFOS concentrations in perch livers from fish caught in the lake. Follow-up investigations identified two suspected major PFAS sources to the lake: a fire station that opened in the 1980s and used AFFF until 2007 (refer to the site profiles for AFFF (CL:AIRE, 2025l) and Fire Suppression Systems (CL:AIRE, 2025m)), and a closed factory that produced paper products from 1964 to 2013. The fire station and former factory are located on the banks of a river flowing into the lake, with the fire station located 11 km upstream from the river mouth, and the factory a further 15 km upstream. The entirety of the sediment bed in Lake Tyrifjorden was found to be contaminated by PFAS. Concentrations and profiles of targeted PFAS in the water and sediment samples from the two suspected sources (fire station and paper production) varied. Water from the storm water system of the fire station was dominated by C5 – C8 PFCA and perfluoroalkyl sulfonic acids (PFSA), while sediments were dominated by PFOS in addition to perfluorohexane sulfonate acid (PFHxS), and 6:2 FTS. Relatively minor levels of C9 and C10 PFSA and PFCA, other PFOS precursors compounds (FOSAA, EtFOSAA) and 8:2 FTS were detected, likely reflecting impurities, or that small amounts of different AFFF products have been used. PFAS profiles in the fire station storm water and sediments were consistent with profiles previously reported for AFFF impacted areas. Water from the creek downstream of the paper factory landfill contained PFOA, PFOS and EtFOSAA as well as a smaller proportion of C5 – C7 and C9 PFCA, FOSA, and FOSAA. Sediment samples from the creek were dominated by 8:2 FTS and 10:2 FTS, smaller fractions of EtFOSAA and 12:2 FTS, in addition to some 14:2FTS, FOSAA, EtFOSE, and PFOS. The paper plate made in the factory was dominated by C6 – C10 PFCA with smaller proportions of C12 – C14 PFCA, 8:2 FTS, and 10:2 FTS. Concentrations and profiles in sediments and biota indicated that emissions originating from the former factory that produced paper products were the main source of pollution in the lake, while no clear indication of fire station emissions was found. Ratios of linear- to branched-PFOS increased with distance from the factory, indicating that isomer profiles can be used to trace a point source. A dated sediment core contained higher concentrations in older sediments and indicated that two different PFAS products have been used at the factory, referred to as Scotchban and FTS mixture. The research paper concluded that production of paper products may have been a major PFAS point source, that had generally been overlooked. It is hypothesised that paper fibres released from such facilities are important vectors for PFAS transport in the aquatic environment (Langberg et al., 2021).

Table 1. Case studies (continued).

2. A German case study
A research project on the Remediation Management for Local and Wide-Spread PFAS Contamination conducted by the German Environment Agency (2020) stated that in the paper industries after PFOS related compounds were phased out, only substances listed in the recommendations of the Germany Federal Institute for Risk Assessment have been used. However, in the past other compounds were used and in agricultural areas treated with compost containing paper sludge PFBA, PFPA, PFHxA, PFHpA, PFOA and PFOS could be found in soil eluates. PFBS, PFNA and PFHxS could also be measured except for a few samples. In addition, traces of PFDA and PFPeS were found in some eluates. PFOS and PFOA are not used directly in the paper industry but occur together with FTOH as impurities or as conversion products in the products.
3. PFAS paper mill lawsuit in Maine (USA)
According to an online news article published by the National Law Review (2021), on March 5, 2021, a class action lawsuit was filed in Maine by residents of Fairfield, Maine, in which they allege that a paper mill company polluted residential land with PFAS and exposed residents to risk of harm to their health, necessitating costly remediation of the contaminated land. The Skowhegan paper mill is a pulping and papermaking facility that manufactures various paper products, including coated paper, grease-proof packaging paper, and bleached chemical pulp. The paper mill has an annual production of 970,000 tonnes of coated paper and 525,000 tonnes of bleached chemical pulp. This paper mill, like many other paper mills across the globe, produces biosolid waste as a result of cleaning and chemically preparing materials for use in the mill's finished product. The biosolid waste is a sludge material that must be disposed of. The waste includes a variety of materials, including waste water sludge, woodyard waste, trash, demolition debris, and ash from boilers. According to the news article (National Law Review, 2021), the paper mill obtained licenses from the state of Maine to spread the sludge material on nearby farms, as it also has fertilising properties that are beneficial to farmers. Since 2020, the Maine Department of Environmental Protection has been investigating PFAS contamination in Fairfield, where at least 29 wells have levels exceeding the US Environmental Protection Agency's maximum limit of 70 parts per trillion (ppt). According to pleadings in the case, in January 2021, one well measurement for one of the named plaintiffs was 12,910 ppt (National Law Review, 2021).

5. KEY PFAS CONTAMINANTS OF CONCERN

The main suppliers and brand names of fluorochemicals used by the paper industry include: 3M, Bayer, Ciba (BASF), Clariant, DuPont, Scotchban®, Baysize®, Lodyne®, Cartafluor® and Zonyl® (UNEP, 2011).

Historical use of PFOS, PFOA, PFSA and PFCA has been identified in the PCM industry (Schaider et al., 2017). However, PFOS-related substances have largely been phased out in OECD countries in favour of fluorotelomer-based substances, phosphates and mechanical processes (UNEP, 2011). A further report by Buck et al. (2011) also identified the use of fluorotelomer-based polymers and polyfluoroalkyl phosphoric acid monoesters. PCM FCM must comply with European legislation on materials and articles coming into contact with food, superseding some of the requirements of REACH.

CONCAWE (2016) reports that historical use of PFAS in the paper and food packaging industry included the following compounds: PFOS, POSF, PFOA, FOSE, FOSA, PFOSE, PFOSA, FTOH, PAP, fluorocarbon resins and EtFOSE.

The Norway Lake case study summarised above identified PFOA, PFOS and EtFOSAA as well as a smaller proportion of C5 – C7 and C9 PFCA, FOSA, and FOSAA within surface waters downstream of the paper mill.

ITRC (2023) report the use of both polymeric and non-polymeric PFAS in paper and packaging. Polymers include side-chain fluorinated polymers in which the PASF- or fluorotelomer-based alcohols or their acrylate or methacrylate esters are attached on side chains. Non polymer PFAS include phosphate ester salts PFPEs.

A study by Thompson et al. (2023) of toilet paper from around the world found 6:2 diPAP as the predominant PFAS.

6. SOURCE POTENTIAL FOR PAPER AND CARDBOARD MANUFACTURING

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2 on the next page.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Process water	5	3	15	Potential release of process effluent. This will be discharged either to sewer or through a site discharge consent to surface water.
Waste water system	3	5	15	May include process waste water and drainage water from working areas. On-site effluent treatment processes unlikely to reduce PFAS content. May be tankered for off-site disposal to WWTW.
Chemical mixture preparation area	5	2	10	Leaks can occur and if good practices are not in place PFAS can reach the drains or surface watercourses via direct runoff.
Waste management area	3	3	9	Release to the ground in areas where production waste/waste water containing PFAS are stored before collection for disposal.
Landfills	3	3	9	On-site landfills which may have received paper waste materials. Leachate can contain PFAS and potentially impact the groundwater.
Concentrates storage area	5	1	5	Leaks can occur and if good practices are not in place, the substance can reach the drains or surface watercourses via direct runoff.
Concrete or other hardstanding areas where PFAS have been used or stored	1	2	2	Past adsorption of PFAS to concrete or other semi-porous surfaces. Slow release of PFAS from concrete can potentially impact surface water and groundwater.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Refineries and Fuel Sites.

Refineries and Fuel Sites

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO REFINERIES AND FUEL SITES

The oil and gas industry can be divided into three sectors: upstream, midstream and downstream. This site profile relates to downstream activities, excluding the distribution of fuel to the point of sale. The midstream and upstream sectors are covered in the site profile for the Oil and Gas Industry (onshore exploration and extraction operations) (CL:AIRE, 2026g).

Activities included in the downstream sector are oil and gas refining, fuel gasification and liquefaction, petroleum distillation, crude oil storage and gathering stations for processing oil and gas. It also includes fuel storage sites. These sites are usually regulated under the Environmental Permitting Regulations (2016) as part A(1) installations, refinery sites are also likely to be COMAH establishments (refer to the site profile for COMAH Regulated Sites (CL:AIRE, 2026b)). In the past, some petrochemical sites are also likely to have been referred to as refinery sites.

The Department of Environment (DoE) Industry Profile 'Oil Refineries' (DoE, 1995) provides a snapshot of oil refinery activities and contamination potential in the early 1990s. Oil refining has been carried out at relatively few locations in the UK, with the location largely dictated by proximity to deep water ports and product markets. Refinery capacity grew in the 1950s and peaked in the 1980s and then declined. In 1995, the DoE stated that most refineries in operation in the UK had been developed over a period of 15–40 years (DoE, 1995). Even where refinery operations had ceased at a site, some site operations such as specialist processes or use as an oil or product terminal continued. This continues to be the case, with a relatively small number of sites, each with a long history of use in oil refinery and storage. According to CONCAWE (2024), there were seven operational refineries in the UK in 2023.

2.1 Use of PFAS

PFAS have uses in the energy industry within evaporation inhibitors, as surfactants, and in fire prevention and protection including foam fire suppression systems (refer to the site profile for Fire Suppression Systems (CL:AIRE, 2026m)).

The key use of PFAS at refinery sites, and other related facilities handling large volumes of flammable and combustible liquids with the potential to cause environmental impact, is associated with the use of AFFF for fire prevention, protection and incident response liquids, and for flammable vapour suppression during 'hot work' (CONCAWE, 2016) (reference should be made to the site profiles for AFFF (CL:AIRE, 2026l) and Fire Suppression Systems (CL:AIRE, 2026m)).

Activities particular to refinery sites, with the potential for loss of PFAS to ground and groundwater are detailed below:

- Fire stations and fire training areas – it was common practice for sites to have their own on-site fire brigade, with associated fire training grounds, where training exercises would take place. Also foam storage, vehicle filling and vehicle washing.
- Foam training exercises associated with emergency planning for incident response – these could take place on the main site as well as in the fire training ground. Modern practice requires containment of foams and runoff, this is likely to have been given less consideration in the past.
- Automatic fire suppression systems associated with fuel storage and activities, requiring regular testing, and maintenance. Accidental loss from fire suppressions systems, including rupturing of pressurised systems.
- Incident response including the standard practice of applying a foam layer to chemical spills and leaks as a fire prevention measure.
- Use of PFAS for flammable vapour suppression during 'hot work'.
- Response to actual fire incidents, where large quantities of foam would potentially be used in firefighting.
- The site drainage and liquid effluent systems will not have been designed for removal of PFAS. Historically, the emphasis on environmental management of refinery site drainage systems is likely to have focused on hydrocarbon separation and treatment through the use of interceptors and oil water

separators in effluent treatment plants. These will have been ineffective in removing PFAS from the waste water. While oil contaminated water will have been disposed of via the oily water treatment system, foam-containing firewater is likely to have been flushed to stormwater drainage systems. Even now where discharges from sites are managed through discharge consents, PFAS are not usually considered within the consented substances.

While some of these activities will be limited to specific areas of the site (for example, the site fire stations), others, such as incident response and emergency training, could take place anywhere on the site. Furthermore, flushing of PFAS-containing water to drainage systems is likely to have resulted in dispersing the PFAS through the site. Leakage from the drainage system can result in loss to ground at some distance from the area of use of the AFFF. PFAS absorbed in silt built up in the drainage system can also act as a long-term source of PFAS release.

The properties of PFAS mean that they may be sorbed onto other materials, for example PFAS may be dissolved in or sorbed onto non-aqueous phase liquids present in the ground, particularly where the AFFF had been applied to the leak or spill and was then lost to ground. PFAS may also be adsorbed onto construction materials including concrete on pavements and in drainage systems, and leached over time.

Modern facilities are expected to have systems in place for the containment of firewater or accidental discharges. This may include use of below ground drainage systems for temporary containment. The effectiveness of containment will be dependent on the condition of site surfaces, bunding, and drainage systems. However, with older sites, improvements may still be in progress and as such there may continue to be credible pathways for PFAS contaminated runoff or firewater to enter the water environment.

3. CASE STUDIES

Case studies identified from a literature review, with examples of PFAS associated with refineries and fuel sites are listed in Table 1.

Table 1. Case studies.

1. Porvoo Refinery, Finland
Reinikainen et al. (2022) describe a case study of a PFAS occurrence at a 1,300 ha refinery site at Porvoo in Finland. The refinery had a fire-fighting training site used by the fire brigade from the 1980s until 2015. The fire training site was remediated in 2016 when a new power plant was constructed, with soil excavation and the removal of an estimated 60 kg of PFOS. Fire-fighting foams were also reported to have been used elsewhere on the site associated with emergency response to fires. In particular, a large fire occurred in 1989 at an isohexane storage tank about 700 m north-east of the former fire training ground. It was reported that an estimated 260 m^3 of AFFF (estimated as up to 2000 kg PFOS) were used to extinguish the fire. The underlying geology comprises heavily modified, fractured bedrock. Most of the surface runoff flows in the uppermost fractures through which the water discharges into ditches or directly into the sea. The majority of surface runoff and waste waters from the refinery are discharged into the sea through three controlled discharge points. According to the conceptual site model, water from the area of the 1989 fire is discharged at a different point from the discharge which received water from the fire training area and the refinery waste water treatment plant. The study focused on surface water discharged from the site sampled between 2016 and 2019. PFOS and PFHxS were the predominant PFAS identified, although the suite of 23 PFAS also included fluorotelomers as well as long and short chain PFSAs and PFCAs. The ratio of PFAS at the northern discharge point (receiving drainage from the area of the 1989 fire) remained fairly constant throughout the monitoring and it was concluded that this indicated a single primary source associated with the fire. PFAS ratios in the southern drainage point were much more variable and were interpreted as indicating a source related to multiple unidentified sources of AFFF used during the site's operational history. Surface water runoff was also monitored upgradient of the third discharge point, a tunnel for cooling water discharge. This surface water was found to have the highest overall PFAS concentrations, and was interpreted as derived at least in part from the fire training ground, indicating that the remediation by soil excavation may not have been successful in terms of PFAS removal. Key observations from this case study include: • The continuing predominance of PFOS in environmental samples despite restrictions in the past two decades; • The relative impact of a single major fire event in 1989 compared to 40 years' use of AFFF at the fire training ground; and • Continuing impact from unidentified sources in the main refinery site even after major soil removal from the identified source area at the fire training ground.
2. Operational refinery, Germany
A research project undertaken by the German Environment Agency (UBA) (2020) on PFAS contamination includes brief details of PFAS contamination associated with an un-named operational refinery in Germany. The refinery site is reported to be diffusely contaminated with PFAS in many areas, associated with use of AFFF in several training areas and also the use of fire extinguishing agents in other areas of the site. The site conceptual model includes 2 m to 4 m of unsaturated soil, and groundwater within a Quaternary aquifer. A groundwater plume has been identified extending about 1.3 km beyond the approximately 1 km long refinery site. Surface water was formerly discharged into a nearby surface watercourse but is now discharged into the site sewage treatment plant, and the surface watercourse is now largely not impacted by PFAS contamination. According to UBA (German Environment Agency, 2020), the refinery operator is being required to install hydraulic containment at the site and further source remediation at individual hotspots is being considered.

Table 1. Case studies (continued).

3. Former refinery / petrochemical site, England
Part of a former refinery / petrochemical site is proposed for mixed use redevelopment. The site operated from the 1940s up until the 1980s. A substantial amount of ground investigation has taken place at the site, however this has largely focused on 'conventional' contamination including NAPL. PFAS were not included in groundwater monitoring or ground investigations until 2019. The following potential sources of PFAS contamination have been identified at the site: • the on-site fire station, with associated foam storage areas; • fire training areas; • foams applied to leaks and spills; • response to fire incidents; • PFAS dissolved in NAPL; • drainage networks; and • remobilisation of PFAS from impacted soil and concrete during rainfall events. The drainage networks were identified as both a secondary source and pathway for potential PFAS contamination. The drainage networks were known to leak and thought to be a pathway by which PFAS enters shallow groundwater. Conversely, shallow groundwater flooding of the drainage network is also thought to contribute to dispersal of PFAS and discharge of PFAS impacted water to surface water.
4. Fuel depot subject to fire, southern England
The depot is used for oil storage and transfer, it includes a tank farm and other related infrastructure. On 11 December 2005, an explosion and fire occurred at the site. The fire was extremely severe, engulfed over 20 fuel tanks and burnt for several days. As a result, a large quantity of water and firefighting foams were used to bring the fire under control (HSE, 2008). Some 250,000 litres of AFFF concentrate were used together with an estimated 25 million litres of water. PFOS was present in some of the foam used (Major Incident Investigation Board, 2008), and according to a report by the Environment Agency (2021), a large proportion of the national inventory of PFOS-related fire-fighting foam was used up in the incident. In addition, a large quantity of fuel was lost to ground. Contaminated firewater was collected in bunded areas on-site. A large volume of this bunded water was removed by tanker off-site post incident and therefore this did not present an ongoing source of potential PFAS contamination on-site. However, a secondary source was formed by the release of fuel and firewater to ground around damaged bunds, and overflow and release via the site drainage system. Substantial remedial works have been undertaken at the site following the incident, including the demolition and removal of existing structures damaged during the fire and removal of soil from contaminated areas. The main pathways for contaminant migration from the on-site source include migration via man-made below ground pathways – e.g. drains, soakaways and along the interface between the ground and buried structures – extending through the largely cohesive superficial deposits resulting in direct infiltration to the underlying chalk; and through leaching/infiltration/leakage of contaminated soil and perched groundwater through the superficial deposits and the vadose zone within the chalk. The main receptors that were impacted by the contamination caused by the incident include groundwater in the Chalk aquifer, and surface waters within 4 km of the site. Monitoring indicates continuing presence of PFAS at these receptors.

4. PROCESS

PFAS may contaminate groundwater through leaching from sites where fire-fighting foams have been applied, including the slow release of PFAS from concrete or other semi-porous surfaces where fire-fighting foams have been used. PFAS may enter rivers, streams, lakes and coastal waters in the form of water runoff and waste water discharge.

5. KEY PFAS CONTAMINANTS OF CONCERN

There is the potential for a wide range of PFAS to be present, with the majority released via AFFF use (refer to the site profile for AFFF (CL:AIRE, 2026l)). The actual PFAS present at any one site will be variable dependent on the AFFF formulations used, which will have varied over time. While some generalities may be drawn associated with the dates of operation and use, and the date of phasing out of PFOS-based AFFF and the introduction of fluorotelomer chemistry, actual practice varied. The operation of UK refinery sites during the 1970s and 1980s means that PFOS is likely to have been in widespread use in a period when environmental controls were fewer, and documented case studies show PFOS to be a predominant contaminant.

As foams have a relatively long shelf life of 10 to 20 years, there is likely to be a substantial stock of legacy long-chain PFAS foams at refineries which have since been withdrawn from the market. A shift to fluorine-free alternatives could be problematic for operators in terms of replacement and disposal costs of legacy PFAS foams (Economics for the Environment Consultancy, 2019) and there is some uncertainty on their technical feasibility for large-scale fire incidents at petrochemical industry sites (Wood Environment and Infrastructure Solutions, 2020).

6. SOURCE POTENTIAL FOR REFINERIES AND FUEL SITES

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Fire training grounds	5	5	25	Historically foams were used directly on the ground and in pits where fire was staged for training. The area would have been washed down after use to remove visible foam, but wash water simply discharged to ground or via an interceptor to the site drainage system. Volume and frequency of use not known. Intense usage of PFAS on concrete pads is likely to have resulted in adsorption of PFAS to the concrete which may continue to be released by leaching over many decades.
Emergency exercise areas	5	5	25	Foam use when testing systems and practicing emergency response in diverse areas of the site, not necessarily restricted to a fire training area. Large quantities of AFFF may have been used and released to the ground.
Foam applied to leaks and spills	4	4	16	A foam blanket was commonly applied to chemical or fuel spills to prevent ignition. Foam and spills could subsequently be lost to ground. PFAS may be dissolved in NAPL.
Fire incidents	4	4	16	AFFF applied to fires of all magnitudes – from fire extinguishers to major incident response. Major incidents have potential for use of very large volumes of AFFF.
Waste water / effluent treatment plants	3	5	15	On-site effluent plants generally designed for treatment of oily water and may be ineffective in reducing PFAS discharge. PFAS may be found in effluent sludge. Below ground drainage network can sometimes form part of the containment system on site during an emergency.
Fire suppression systems	3	3	9	Foam fire suppression systems may be a source of release during testing and maintenance, system failure, or accidental triggering. In the past, testing is likely to have required active release of foam. Foam released due to accidents or testing is likely to have been collected and discharged via site drainage system. Even if foam suppression systems have been converted to PFOS-free or fluorine-free foams, there may still be carryover of PFAS from previous foams used.
Fire stations (including foam storage)	2	4	8	Foam containing PFAS stored in tanks within fire stations, fire engines and pumps at vehicle fill points. Release to the environment may be via accidental spills. It is considered that low quantities of PFAS may be released at these locations. Current tanks may be provided with leak alarms and fire engine with sophisticated systems to avoid spills.
Tank farms / fuel farms	5	1	5	Fuel farms are likely to have foam fire suppression systems with foam stored in tanks. Major release may occur during an accident, with minor releases from accidental spills from the tanks or during system tests.
Surface water drainage	1	3	3	Surface runoff and fire water draining to stormwater drainage systems. Sediments likely to be contaminated by PFAS and to slowly release PFAS to the water environment.
Concrete or other hardstanding areas where PFAS have been used	1	2	2	Past adsorption of PFAS to concrete or other semi-porous surfaces. Slow release of PFAS from concrete can potentially impact surface water and groundwater.

PFAS Site Profile

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

CL:AIRE

PFAS SP 10
(July 2026)

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing.

Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);

- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO TULAC MANUFACTURING

This site profile covers the Textiles, Upholstery, Leather, Apparel and Carpets industries, jointly referred to as TULAC (Wood Environment and Infrastructure Solutions, 2020; REACH, 2021). The TULAC group of industries is one of the most extensive users of PFAS. The properties of PFAS including water and oil repellence and chemical inertness have numerous applications in home textiles, consumer apparel, specialist textiles and more. PFAS impregnation or surface coatings are used for stain and dirt repellence, and other textile enhancements including thermal resistance, durability and 'breathability'. Similarities of the manufacturing process are noticed in the use of PFAS in this group of industries, and they are therefore considered together in this profile.

This site profile largely refers to TULAC manufacturing sites and does not include the manufacture of goods from imported materials which have been treated elsewhere, retail of manufactured goods, use of the goods, and waste, recycling or end-of-life considerations. It also does not include treatment at the point of sale. All of these activities have the potential for PFAS release to the environment.

2.1 Use of PFAS

According to studies completed by MIDWOR (2018), Wood Environment and Infrastructure Solutions (2020), the US EPA (2021) and the Danish Ministry of the Environment (2005), PFAS have been used for a wide range of functional applications within TULAC. Manufacturers use PFAS to impart outdoor gear, clothing, household fabrics, carpets, awnings, footwear and other textile and leather products with the following properties:

- Water, oil, soil, and heat resistance;
- Improve cleanability of oil- and water-based stains;
- As a wetting or antifoaming agent when dyeing and bleaching; and
- As a breathable moisture barrier to wind and rain.

The oil repellence component in particular has been of greater importance for high performance textiles, in particular, certain types of personal protective equipment (PPE) and non-clothing technical textiles (e.g. transport textiles, medical textiles, industrial textiles) which have a wide range of applications.

PFAS have been applied to a large number of products, including (but not limited to), tablecloths, upholstery, bed linen, rainproof clothing, children's clothing, clean room garments, fast food restaurant work-wear, mechanics overalls (RPA Ltd, 2004), awnings, umbrellas, shoes and boots.

PFAS-containing treatments can be applied:

- During the manufacturing of the fibres;
- During the garment or product manufacturing process;
- After the manufacturing process at a separate finishing facility;
- In stores at the time of sale; and
- Following sale, by consumers or professional cleaners.

In the leather industry, fluorinated surfactants have uses in various leather manufacturing processes as well as repellent treatments for the final product (Kissa, 2001). They have been used in hydrating, bating, pickling, de-greasing and tanning.

According to Wood Environment and Infrastructure Solutions (2020), the textile industry is one of the most extensive users of PFAS. Overall, textile applications can account for an estimated 35% of the demand for fluorotelomers globally. This demand was projected to grow by 14% between 2018 and 2020. It was estimated that 45,000 to 80,000 tonnes of PFAS are consumed in TULAC products

in the EU annually. The two key dominant TULAC sectors using PFAS are shown to be home textiles (50–53%) and consumer apparel (34–39%). This estimate, made by Wood Environment and Infrastructure Solutions, is based on the tonnage of TULAC products that are sold in the EU market annually, which will include both products manufactured in and imported into the EU. Due to the lack of available data, it is difficult to differentiate between the volumes of PFAS present in manufactured and imported TULAC products.

Studies by Risk and Policy Analysts Ltd (RPA Ltd, 2004) and the Danish EPA (Danish Ministry of the Environment, 2005) documented a notable change in the use of PFAS in the TULAC industry in the early 2000s, with the move away from formulations based on PFOS or its precursors as awareness grew over the hazards posed by C8 PFAS. The 3M company announced phasing out of PFOS and PFOA from production in May 2000, and in June 2003, PFOS was replaced by PFBS in the 3M Scotchgard brand of fabric protector (Danish Ministry of the Environment, 2005). In 2022, 3M announced it would exit PFAS manufacturing and work to discontinue the use of PFAS across its product portfolio by the end of 2025 (3M, 2022).

In general, industrial application of PFAS to TULAC primarily occurs within textile mills or leather tanneries during the manufacture of the fabric (prior to creating a garment). Surface treatments (such as antimicrobials or stain resistance) are often applied during the final stages of manufacturing. Some manufacturing companies declare that they use a closed loop water cycle, but in older manufacturing processes, waters and chemicals were potentially discharged to drains.

Leather goods are identified as having high concentrations of PFCAs/ PFSAs in laboratory testing (Kotthoff et al., 2015). Kissa (2001) reported that 2–3% PFAS (by weight) is required to obtain water repellence in textiles, but only 0.025–0.05% in leather.

2.2 Information from RPA 2004 Review of PFAS Use in Textiles

A PFOS Risk Reduction Strategy undertaken by RPA for Defra/ Environment Agency in 2004 (RPA Ltd, 2004) provides some interesting insight into the use of PFOS and related substances in TULAC industries in the UK prior to that date, and following the withdrawal of PFOS based formulations from the market by 3M. The RPA (2004) report states that in 2004 there was no current use of PFOS related substances in textile or leather applications in the UK and use was considered to be historical.

RPA included UK carpet manufacturing in their study (RPA Ltd, 2004). PFOS related substances have been used to treat carpet fibres to prevent the adherence of oil, liquid spills, stains and grit to the surface; they have also been used as spot cleaners. RPA suggested that 95% of all carpet protectors based on PFAS are for application at point of manufacture in the carpet mill. In the mill there are three main ways that PFAS can be applied to the carpet fabric:

- Foam application;
- Dye-bath application; and
- Spray application.

However, RPA stated that consultation with UK carpet association and carpet manufacturing gave little or no information and it was not possible to estimate the size of the market (RPA Ltd, 2004).

The RPA report (RPA Ltd, 2004) highlighted the difficulty in finding specific information about the chemical formulations used in TULAC treatments due to the extended supply chain and limited information provided by the producers. Their consultation indicated that individual user companies generally purchased technical chemicals (auxiliaries) from suppliers, and relied on information provided in the suppliers material safety data sheets (MSDS) for information on composition, environmental and human health effects. However, it was noted that MSDS only provide basic information and much of the detail was withheld as being commercially sensitive. RPA also consulted with the specialist chemical suppliers, and found that they also had limited knowledge with regards to the exact chemical composition of the substances they purchased, and they also relied on the MSDS provided by the producers. While these may acknowledge the use of perfluorinated chemicals they did not provide exact detail. It was concluded that only the original producers would be in a position to state categorically if a formulation contained PFOS or other perfluorinated chemicals, and they would not disclose the amount or concentration of PFOS in their formulations.

The RPA consultation (RPA Ltd, 2004) also found that at that time a ‘significant proportion’ of the suppliers of technical chemicals had their manufacturing plants in Europe, where most production took place, and the UK supplier companies were mainly involved in distribution, not manufacture. It was also noted that ‘a significant number’ of the supplier companies indicated that they obtained their perfluorinated chemicals from Japan.

Enquiries undertaken as part of the Environment Agency PFAS Risk Screening project indicate that the general situation in 2022 was not dissimilar.

2.3 Information from Danish EPA 2015 Review of PFAS Use in Children’s Clothing

In 2015, the Danish EPA published a detailed review focusing on PFAS use in children’s clothing which provides further insight into the methods and markets at the time of the study (Danish EPA, 2015). The report contains extensive other information relating to the occurrence and risks associated with PFAS in children’s clothing which is not directly relevant to this site profile.

They identified PFAS use in particular within impregnating agents and in waterproof membranes.

2.3.1 Impregnation Agents and Fabric Protectors

According to this study, the impregnating agents “typically consist of a mixture of reactive PFAS, other reagents and solvents. The impregnating agents are applied as a thin film to the surface of the fabric, followed by polymerization and curing, whereby a thin polymer structure is formed on the surface, to which both polyfluoroalkylated and non-fluorinated side chains are attached. The side chains, which extend as small hairs from the material, aid in providing the dirt and water repellent effect. The fluorinated side

chains are similar in structure to PFAS, and have a perfluorinated moiety of varying length. The non-polymeric PFAS, which can be extracted from the cured fabric, consist partly of unreacted intermediates and partly of PFAS released by hydrolysis of the ester bond between the side chains and the polymer."

The composition of commercial fabric protecting impregnation products is confidential, but they are known to comprise complex substances and polymers. These may include substituted perfluoroalkyl sulfonamides or polyfluoroalkylated (telomer) acrylates, urethanes, phosphates or sulfonates as well as simpler perfluoroalkyl sulfonamides or fluorotelomer alcohols. The study illustrated a typical 'product chain' for impregnation agents, showing how the PFAS product is produced by an international manufacturer such as Du Pont, which are then used by an intermediate company to make textile finishing agents, and supplied to the mills and finishers. The mills and finishers then apply the finishing agents. The textile producers do not therefore have a direct relationship with the PFAS producers. The product chain becomes even longer and less certain with imported goods. The Danish EPA found no information to suggest that there would be significant differences between products produced in Europe and products produced in China or elsewhere in Asia, however, it could not be excluded that in certain places of the world, significantly different impregnation agents may be used, including for example non-polymer PFAS.

Although the composition of impregnating agents is confidential, some research has been undertaken investigating the composition of treatment agents (prior to polymerisation and curing) which were summarised in the Danish EPA report. High concentrations of fluorotelomer alcohols (FTOH) were found in studies in Sweden, Canada and Norway, including between 0.2 and 9 g/l FTOH (200,000 to 9,000,000 µg/l) in Sweden in 2007. Samples from Sweden and Norway from 2009 also contained very high concentrations of FTOHs, including 6:2 FTOH (up to 0.013 g/l), 8:2 FTOH (up to 0.33 g/l) and 10:2 FTOH (up to 0.12 g/l). PFCAs were also detected but at lower concentrations (6–1200 µg/l).

2.3.2 Waterproof Membranes

The Danish EPA (2015) report also considers the PFAS present in polytetrafluoroethylene (PTFE) membranes (such as Gore-tex®) used to make clothes waterproof. PTFE may contain non-polymeric PFAS such as PFOA and PFNA as residues of processing aids used in the PTFE manufacture. The Danish EPA noted that at the time of writing alternative processing aids were being used to a great extent, but it was not possible to find information on which materials were being used. They note that various PFAS have been found in analysis of clothes with Gore-tex® membranes, however none of the studies exclusively reported the analyses on the membrane, so interpretation is difficult, as clothes with membranes are also treated with impregnating agents.

2.4 European Commission Study by Wood Environment and Infrastructure Solutions, 2020

The European Commission contracted Wood Ltd to study the use of PFAS and fluorine-free alternatives in textiles, upholstery, carpets, leather and apparel, including specific focus on volumes of use, technical function, and emissions (Wood Environment and Infrastructure Solutions, 2020).

The study highlighted that water, oil and dirt repellence were the primary functions for use of PFAS in textiles, with other functionality such as thermal resistance and 'breathability' for certain types of clothing. The oil repellent properties of PFAS had particular application in high performance textiles, including certain types of PPE including in medical applications.

Two broad groups of PFAS were identified to be in use in TULAC – fluoropolymer compounds and non-polymer PFAS. The fluoropolymer compounds included both side-chain fluoropolymers, largely based on fluorotelomer acrylates and urethanes, as well as fully perfluorinated polymers such as PTFE. The non polymeric PFAS identified to be in use included both short and long chain PFAS including fluorotelomers and substances based on perfluoroalkane sulfonyl fluoride (PASF), including sulfonamides and sulfonamidoethanols.

Market data were compiled and indicated that 45,000 to 80,000 tonnes of PFAS are consumed in TULAC products in the EU annually, predominantly in home textiles (50–53%) and consumer apparel 34–39%).

3. CASE STUDIES

Limited examples have been identified in the scientific and grey literature relating to environmental contamination resulting from textile manufacturing other than related to waste water effluent discharges. Some identified examples are briefly described in Table 1.

4. PROCESS

The primary manufacturing process by which PFAS are likely to be used in large quantities in textile manufacturing is within impregnating agents used for fabric treatment, as well as surface treatments and coatings. These may involve wet application within a treatment bath, or spray application. Modern systems may use closed loop systems. All processes have the potential to generate waste water containing PFAS, in varying quantities and concentrations.

Release of PFAS to the environment might therefore be expected via the following routes:

- Accidental loss from storage and use of concentrates;
- Process water and effluent;
- Waste water effluent – to off-site waste water treatment plants, or to on-site water treatment plants and subsequently as effluent discharge, as normal water treatment processes are unlikely to significantly remove PFAS; and
- Disposal of waste material off-cuts to landfill.

5. KEY PFAS CONTAMINANTS OF CONCERN

A variety of PFAS have been used and are in use for TULAC applications.

According to the 2021 REACH Report Summary for TULAC (REACH, 2021), at the time of the study around 120 PFAS were identified in the TULAC sector in the European Economic Area, either used intentionally or present as the product of degradation or impurities. It was indicated that 82 of these had CAS numbers and many were

PFAS Site Profile

Table 1. Case studies.

1. Wolverine tannery site, USA
One of the most reported incidents of PFAS environmental contamination in the USA relates to PFAS contamination of residential wells from Wolverine's former tannery, shoe factory, and disposal locations in the Rockford area of Michigan. It is understood that activities at the site included disposal to landfill of leather off-cuts, and sludge spreading to land. Drinking water was contaminated with both PFOS and PFOA, and other unspecified PFAS (US EPA, 2022).
2. PFAS in textile waste water in China
Several studies have been identified documenting PFAS in waste water from textile plants in China. Heydebreck et al. (2016) investigated the occurrence and distribution of PFAS in waste water, air, airborne particles, and settled dust in a textile manufacturing plant in China. PFOA and PFDA or their precursor compounds 8:2 FTOH and10:2 FTOH were the dominant compounds in all environmental media tested, with a maximum of 2076 ng/l PFOA in one effluent sample. FTOH were not analysed in the dissolved phase water samples, but the analysis did include fluorotelomer unsaturated carboxylic acids (6:2 FTUCA, 8:2 FTUCA, and10:2 FTUCA), which are intermediates formed during biotransformation or aerobic biodegradation of FTOHs to PFCAs. The presence of relatively high concentrations of FTUCAs in the effluent water (up to 658 ng/l 8:2 FTUCA), indicate that the PFCA findings have resulted from the use of textile finishes that are based on FTOHs. Gu et al. (2021) measured 17 PFAS in regulation tank influent and final effluent from 48 textile plants in the Yangtze River Delta. The PFAS studied were limited to PFCAs and PFSAs, and they reported a median sum of 17 PFAS concentrations in influent and effluent of 428.5 ng/l and 268.0 ng/l, respectively. They noted the concentration of PFAS varied with the raw textile materials, ranked in the order of chemical fibres > knitted fibres > greige cloth (unfinished loom cloth) > cotton > wool fabric > silk. Ma et al. (2022) looked at long-term trends of fluorotelomer alcohols in a municipal waste water treatment plant receiving textile manufacturing waste water between 2013 – 2016, and 2021 – 2022. They detected total concentrations of FTOHs of 9.8–43 ng/l in the influent and 5.9–29 ng/l in the secondary effluent. They noted a substantial decline in the proportion of long chain FTOH, in particular 8:2 FTOH, over time indicating a move towards short chain 6:2 FTOH in line with growing restrictions on PFOA precursors. Jia et al. (2023) investigated 27 legacy and emerging PFAS along the processes of three full-scale textile dyeing waste water treatment plants. They found various emerging PFAS present in different abundances at the three different plants. In one plant PFOA, PFNA and 6:2 FTS were predominant, while in the second plant the ethers 8:2 Cl-PFESA and HFPO-DA were most abundant. In a third plant 8:2 Cl-PFESA, 8:2 FTUCA, HFPO-TA and HFPO-DA were predominant. Total Oxidisable Precursor (TOP) Assay at all sites showed a substantial increase in measurable PFAS (both long and short chain) indicating the presence of precursors. These studies demonstrate the substantial potential for textile manufacturing and treatment to be a source of PFAS emissions to the environment, with a varied and changing range of PFAS compositions in the effluent.
3. PFAS in waste water in a textile district in Italy
Cantoni et al. (2024) presented a study of a textile district in Como province (Italy), where 42 textile factories discharge waste water in a municipal sewer system which conveys the mixed waste water (textile and urban) to a municipal WWTW. Monitoring for 15 PFAS was undertaken at four textile factories representative of the textile district: a textile printing, a fabric dyeing and two yarn dyeing factories. The monitoring shows the consistent presence of PFAS, despite the commitment of textile factories to phase out these compounds. In the waste water treatment works influent, a maximum of seven (PFBA, PFBS, PFHxA, PFPeA, PFHpA, PFOA, PFOS) out of 15 PFAS were detected, with an average sum concentration of 0.44 µg/l. These PFAS were all present in the urban waste water, while PFBS and PFOS were never detected in textile waste water. The textile waste water was found to be mainly characterised by short-chain PFAS (91.7% of the total PFAS).
4. US EPA Multi-Industry Study – Textile Mills
US EPA (2021) documented that PFAS have been, and continue to be, used by textile mills in the USA. The study did not identify any textile mills with PFAS effluent limitations or pre-treatment standards in their waste water discharge permit and it was estimated that only a small fraction of textile mills monitor for PFAS. They did not identify any textile mills employing waste water treatment systems known to effectively reduce PFAS in industrial waste water. The study identified that there were around 6000 establishments in the USA manufacturing textile products, and that a 2016 market study concluded that the global textile industry was the largest user of fluorotelomers by volume, making up about 35% of the total market. As part of the study, the US EPA attempted to meet with industry stakeholders to obtain, on a voluntary basis, information on the use and discharge of PFAS for textile and carpet mills. The industry trade bodies declined to meet with the US EPA or provide any information, and only limited information was provided by carpet manufacturers, one major manufacturer citing ongoing litigation with regard to alleged PFAS discharge as a reason not to respond. The US EPA did obtain a small number of waste water analysis results which showed that PFAS, including legacy long chain PFOS and PFOA, were present in some waste water discharges. This study illustrates the challenges in obtaining information from this sector.

PFAS Site Profile

Table 1. Case studies (continued).

5. Perfluoroalkyl and polyfluoroalkyl substances in consumer products, Germany
A study undertaken by Kotthoff et al. (2015) analysed various textiles (including outdoor materials, gloves and leather) purchased in Germany for PFSA, PFCA and FTOH. The study found that outdoor materials and gloves analysed did not contain PFSAs but did contain PFCAs and very high concentrations of FTOHs. Leather samples contained both PFCAs and PFSAs (and were not tested for FTOHs), with the highest concentrations of short chain PFCAs. Kotthoff et al. (2015) analysed six carpet samples for PFSA and PFCA, and eight carpet samples for FTOH. PFCA of all chain lengths from C4 to C12 were recorded in samples, with PFBA the most abundant, and present in 50% of samples. Of the PFSAs, only PFBS and PFOS were detected in any carpet samples, with the highest concentrations being of PFBS, but with PFOS present in more samples. 6:2 FTOH and 8:2 FTOH were present in all materials tested with 8:2 FTOH present at the highest concentration of all PFAS (Kotthoff et al., 2015).
6. PFAS from carpet and clothing in model anaerobic landfill reactors, USA
Lang et al. (2016) studied PFAS release from clothing and carpet waste in the USA, observing the aqueous phase of anaerobic model landfill reactors filled with carpet or clothing and monitored under biologically active and abiotic conditions. The study identified that the primary PFAS in the leachate released from the carpet in the aqueous phase comprised short chain PFCAs, PFOA, and 8:2 FTSA, with some of these substances likely to be derived from telomeric precursors. Lang et al. (2016) studied PFAS release from discarded carpet, including used carpet and new carpet offcuts, in the USA. They identified the primary PFAS in the leachate released from the carpet in the aqueous phase comprised 5:3 FTCA, 6:2 FTCA and PFHxA, with some of these substances likely to be derived from telomeric precursors (Lang et al., 2016).
7. Carpet manufacturing in the Kidderminster area
The Kidderminster area in the UK West Midlands has been well known as a centre for carpet manufacturing since the 18th century. Historical maps show that a large proportion of the low-lying land along the River Stour, Staffordshire and Worcester Canal in central Kidderminster was used for carpet manufacturing at some time. Over time, carpet manufacturers moved out of the central area with new factories constructed in industrial estates on the edge of town. At the current time there appear to be only a small number of carpet factories remaining in business in Kidderminster, mainly apparently producing bespoke and high-end carpets. Tyler-Whittle et al. (2002) discuss the relationship between the carpet industry and the water environment in the area. Local rivers and streams were used both as a source of power and as a source of the large volume of water required for carpet manufacture; groundwater sources were also exploited for process water. Surface waters were also used for the disposal of waste effluent from the carpet manufacturing industry and Tyler-Whittle et al. (2002) also describe the past impact on water quality of the rivers, from wool dye and discharges of organic matter, solids and grease. Whilst these issues are reported to have been resolved by 2002, with the diversion of effluent to sewage treatment works, the river has continued to be affected by persistent carpet treatment chemicals including permethrin (used as a mothproofing agent). Tyler-Whittle et al. (2002) make no reference to PFAS or stain-proofing chemicals, which were not widely recognised as potential contaminants of concern associated with the carpet industry at the time. In 2021, a review was undertaken of information that had been submitted for planning applications for redevelopment of sites in the area with a history of carpet manufacture; no evidence was found that PFAS had been identified as contaminants of concern at these sites, even as recently as 2019. A review of landfill information identified several landfills in the Kidderminster area that appeared to have received waste from carpet manufacturing, including municipal waste sites where carpet waste was recorded in the waste types, and other sites with names reflecting carpet manufacturers. There was no indication that PFAS had ever been investigated associated with these sites. No specific information linking carpet manufacturing in the Kidderminster area to impact on related to actual occurrence of PFAS in environmental media was identified.

polymers without a CAS number. The majority of substances reportedly in use in the TULAC sector were fluoropolymers (particularly PTFE) and side-chain fluorinated polymers. The list of PFAS used in the sector was not included in the report for business confidentiality reasons. Non-polymeric PFAS are likely to be produced by the degradation of side-chain fluorinated polymers.

The study by Wood Environment and Infrastructure Solutions (2020) identified that fluoropolymer compounds appear to be the dominant PFAS in use for TULAC, including side-chain fluoropolymers based on fluorotelomer acrylates and urethanes and fully perfluorinated polymers such as PTFE. They also identified non-polymeric PFAS used in TULAC including PFCAs, PFSAs, sulfonamides, sulfonamidoethanols and fluorotelomers including (5:3 FTCA, 6:2 FTCA, 8:2 FTOH). The research shows that it is difficult to identify if individual substances were used intentionally, or are the product of degradation, or an impurity.

The Danish EPA study (2015) demonstrated the presence of very high concentrations (up to 0.3 g/l) of fluorotelomer alcohols in impregnation agents used in textile finishing, that may be widely used in UK manufacturing. These included both long chain FTOHs (8:2 FTOH and 10:2 FTOH) with the potential to transform to long chain PFCAs including PFOA, and short chain FTOHs (6:2 FTOH). In China, Ma et al. (2022) suggest a transition towards predominant short chain FTOHs in recent years, while Jia et al. (2023) indicate use of emerging PFAS including PFAS ethers such as HFPO-DA and HFPO-TA.

Environmental monitoring of waste water, surface water and groundwater rarely includes FTOHs because their volatility means that they are not suitable for analysis by the targeted Liquid Chromatography Mass Spectrometry (LCMS) method used for the PFAS in readily available analytical suites. The study by Ma et al. (2022) demonstrated the high concentrations of FTOH which could be detected in textile waste water when included in the analytical suite. FTOH transform in the environment to PFCAs. TOP Assay in

waste water samples by Jia et al. (2023) demonstrated the presence of unidentified precursors in the effluent, which may have included FTOH.

The composition of PFAS used in textile manufacturing has changed over time. Prior to 2001, PFOS and PFOA (and their precursors) are likely to have been predominant in textile treatments, and they appear to have been replaced with more complex substances. Many of these substances are themselves precursors to long and short chain PFCAs and PFSAs. While there are indications of transition in the industry from long chain precursors (such as 8:2 FTOH, a precursor of PFOA) to short chain precursors and PFAS (such as 6:2 FTOH and PFBS) there appears to be little transparency in the supply chain and end users may have little knowledge of the actual composition of the chemicals they use.

It is clear that textile manufacturing has the potential to be using or have used a very wide range of PFAS, at substantial concentrations, some of which are included in suites readily available in the UK and some of which are rarely monitored. While the literature reviewed here provides some insight into the breadth of PFAS used in the textile industry and present in effluent, there are many PFAS potentially present that have not been tested for in the studies evaluated. These include for example short chain sulfonamides which are becoming of increasing concern for environmental toxicity. Substantially more research and testing for a wide suite of potential PFAS contaminants is required.

6. SOURCE POTENTIAL FOR TULAC MANUFACTURING

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as “ITRC (2023)” was substantially updated in January 2026.

Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Process water	5	3	15	Potential release of process effluent. This will be discharged either to sewer or through a site discharge consent to surface water.
Dye-bath	5	3	15	PFAS mixed with other chemicals and water can enter the fabrication process at the dye stage. Residuals disposed via drainage to waste water treatment works or landfill operator.
Waste water system	3	5	15	May include process waste water, wash water and drainage water from working areas. On site effluent treatment processes unlikely to reduce PFAS content. May be tankered for off-site disposal to WWTW.
Chemical mixture preparation area	5	2	10	Leaks can occur and if good practices are not in place, the substance can reach the drain via surface runoff.
Spray areas	5	2	10	Usually enclosed area with dedicated drains. Residuals containing PFAS may be washed out into the drains. Drains may be periodically cleaned, and waste water discharged or disposed of via landfill operator.
Concrete areas and other semi-permeable surfaces where PFAS have been used	2	5	10	Past adsorption of PFAS to concrete and other semi-permeable surfaces. Slow release of PFAS from concrete can potentially impact surface water and groundwater.
Waste management area	3	3	9	Release to the ground in areas where production waste or waste water containing PFAS is stored before collection for disposal.
Landfills	3	3	9	On-site landfills which may have received off-cuts containing PFAS. Leachate can contain PFAS and potentially impact the groundwater.
Concentrates storage area	5	1	5	Leaks can occur and if good practices are not in place, the substance can reach the drain via runoff.

PFAS Site Profile

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

CL:AIRE

PFAS SP 11
(July 2026)

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Waste Water Treatment Works.

Waste Water Treatment Works

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

1.3 Methodology for Calculating Source Potential

For the purposes of the risk prioritisation project for which these site profiles were originally developed, an overall source potential has been developed for each site profile, based on professional judgment informed by the literature review. The source potential is constructed considering the magnitude and likelihood of PFAS presence and use in site profile zones.

The magnitude has been developed with a score of 1–5 (1 – low; 5 – high) based on the expected quantum of PFAS in the activity in the zone. For example, fire training practice using AFFF is recorded as high magnitude, because of the high volume and concentration of PFAS in this activity. Aircraft maintenance using hydraulic fluids containing PFAS is low magnitude because of the relatively low volume and concentration.

The likelihood for each activity is scored 1–5 (1 – low; 5 – high) based on the likelihood of a release to the environment occurring, taking into account frequency of activities where release may occur, and likelihood of loss of containment. For example, fire training practice using AFFF is likely to take place regularly at the same location over a period of years, with potential loss to ground or surface water, so is scored high. Although aircraft maintenance is likely to be undertaken all the time, significant accidental loss of containment is likely to be infrequent, so this is scored low.

The magnitude and likelihood are then multiplied to give the source potential (scored 1–25). It should be noted that these scores are generic and subjective and are based on professional judgment and should continue to be refined as more information becomes available. Further refinement could include expansion to consider changes in practice over the years as pollution prevention practices have improved.

2. BACKGROUND TO WASTE WATER TREATMENT WORKS

Waste Water Treatment Works (WWTW) are potential receivers of PFAS-containing materials within waste waters received from domestic and industrial users.

Domestic sewerage will likely contain PFAS from a very wide range of diffuse sources, including (but not limited to): toilet paper, cosmetics, soaps, detergents, sun cream, stain protection products, waterproof clothing, treated textiles, packaging, food contact materials, cookware and coatings, and human waste. The washing of certain protective clothing, such as those used by firefighters and the military, could also represent a significant PFAS source, either resulting from leaching of PFAS embedded into the fabric or washing of clothes contaminated during AFFF deployments (refer to the site profile for AFFF (CL:AIRE, 2026l)).

Another potential pathway for PFAS contamination of waste waters, is through surface runoff in roads, car parks, airports, and other urban/residential areas during rainfall events. Pluvial sewer waters may be treated separately or mixed with other influents, once received at the WWTW, depending on site design.

Industrial WWTW may receive PFAS impacted waters from a diverse range of uses, including both specific processes which use PFAS, and from use of PFAS containing materials (refer to the site profiles for Metal Manufacturing and Finishing (CL:AIRE, 2026e), Paper and Cardboard Manufacturing (CL:AIRE, 2026h) and Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) (CL:AIRE, 2026j)). WWTW may also receive waste water from the use of AFFF in fire-fighting activities, training, testing and maintenance of fire suppression systems, and accidental losses (refer to the site profiles for AFFF (CL:AIRE, 2026l), Fire Suppression Systems (CL:AIRE, 2026m), Fire-Fighting Grounds and Fire Stations (CL:AIRE, 2026k), COMAH Regulated Sites (CL:AIRE, 2026b), Refineries and Fuel Sites (CL:AIRE, 2026i)). Residual PFAS may continue to be present in waste water effluent long after their use on a site has been discontinued, as a result of past sorption and continued release from permeable media including concrete.

WWTW may also be receivers of landfill leachate, either directly through sewage discharges, or indirectly in tankered waste. PFAS have been found to be ubiquitous in raw and treated landfill leachate.

In summary, where waste water is collected through control processes to prevent discharge of untreated water to the environment, it is likely to end up at a Waste Water Treatment Works (WWTP) and therefore WWTW become a ‘collector point’ for many sources of PFAS. As PFAS are emerging contaminants, in the UK there is currently very little management or control of PFAS concentrations in trade effluents.

WWTW may also be a source of PFAS to the environment, through direct spills and loss to ground, through liquid effluent discharge, through sludge disposal and through reuse of biosolids. Standard water treatment methods currently used in the UK are not effective at removing or destroying PFAS, although some PFAS precursors are transformed within WWTW and there is some partitioning between the liquid (effluent) and soil (sludge) phases, meaning that the effluent is compositionally different to the influent. The concentrations of some terminal products can thus be found to be higher in the effluent than they are in the influent.

PFAS are found in untreated waste water treatment sludge, and in biosolids (treated sludge which can be recycled to agricultural land as organic manure). In the past, sludge may have been deposited to land at WWTW. Currently around 87% of UK waste water sludge is recycled to agricultural land as biosolids. While there are quality standards that must be adhered to for the production of biosolids for agricultural use, these do not currently include reference to PFAS. As this site profile focusses on potential impacts to the environment from PFAS sources associated with the location of the WWTW themselves, the environmental impacts of biosolids recycled to agriculture are not considered further here.

PFAS Site Profile

3. CASE STUDIES

PFAS associated with WWTW have been studied extensively in various countries around the world with numerous scientific publications as well as other industry studies and reviews. ITRC (2023) provides a summary of some recent relevant publications and studies, with a focus on US practice and experience. Table 1 summarises some examples of studies from around the world and the UK.

4. PROCESS

PFAS enter the WWTW via influent flow or tankering (for example landfill leachate) and exit the WWTW via effluent. The influent passes through stages of treatment train, which varies between sites. Treated liquid effluent is discharged to surface water or via soakaway to groundwater. PFAS composition and concentration change through the treatment process as PFAS are transformed and partition between solid and liquid phases. Precursor transformation can result in substantial increases in intermediate PFAS (such as 6:2

Table 1. Case studies.

1. Municipal waste water treatment plants in the USA
Thompson et al. (2022) provide an overview of PFAS in municipal waste water treatment plants in the USA. They note that PFAS are ubiquitous in municipal waste water and biosolids, and while there are major point sources from industrial activities, PFAS have been detected in waste water even without direct industrial sources, such as in septic tanks and office buildings. They note that some PFAS in waste water effluent can be ascribed to PFAS in the community drinking water supply. Their meta-analysis of long term trends based on multiple published studies concluded that concentrations of long-chain PFAS, particularly PFOA, declined over time in waste water effluent, while concentrations of short chain PFAS such as PFBA may be increasing. They concluded there was a long term trend away from industrial contributions of PFAS to WWTW, to a higher proportion of the PFAS in WWTW influent coming from domestic waste water.
2. WWTW effluent and sludge in seven Nordic countries
Aro et al. (2021) studied effluent and sludge samples from WWTW in seven Nordic countries. They used Extractable Organic Fluorine (EOF) and a list of 73 target PFAS to evaluate which compounds are released back into the environment. Based on the fluorine mass balance analysis of the effluent they estimated that on average 90% of the EOF could not be explained by the target analysis. Ultra short chain PFAS (C2 – C3) were identified as accounting for 4% of the EOF, while the remaining target analysis explained only a further 6% of EOF on average. The largest contributors were short chain PFCAs (C4 – C7), followed by long chain PFCAs and PFSAs. The predominant precursor and intermediate compounds identified were 5:3 FTCA, 6:2 FTSA and 6:2 diPAP. Trace levels of PFECHS were detected in some effluent samples. Unknown intermediate and precursor PFAS with the potential to transform into PFAAs were considered likely to be significant contributors to the unknown organofluorine. Fluorinated pharmaceuticals are proposed as a further source of up to 18% of the EOF. Aro et al. (2021) found less unidentified organofluorine mass in sludges compared to effluent, with around half the organofluorine accounted for by target compounds. The PFAS class accounting for the majority of the identified EOF in sludge were diPAP, with 5:3 FTCA, EtFOSAA and MeFOSAA also substantially present. PFCAs and PFSAs made up around 10% of the EOF and were predominantly long chain. Potential sources of organofluorine were postulated to be fluorinated polymers and perfluoropolyethers (or side-chain-fluorinated polymers).
3. PFAS in Canadian municipal waste water
Gewurtz et al. (2024) studied PFAS in Canadian municipal waste water and biosolids and assessed time trends of PFAS in waste water from 2009 to 2021. The concentrations of PFAS were determined in raw influent, final effluent, and treated biosolids at Canadian WWTPs to evaluate the fate of PFAS through treatment trains and to assess time trends of PFAS in waste water between 2009 and 2021. Data for 42 PFAS in samples collected from 27 WWTPs across Canada were used to assess current concentrations and 48 WWTPs were included in the time trends analysis. They found that PFOS, PFOA and other long-chain PFAS continue to be widely detected in Canadian waste water and biosolids despite having been phased out from new uses, although (with the exception of PFOS) concentrations of long chain PFAS were found to have declined over time. Short-chain PFAS were also widely detected, and concentrations of short-chain PFCAs in waste water influent and effluent consistently increased between 2009 and 2021, reflecting the use of short-chain PFAS as replacements for phased-out and regulated longer-chained PFAS. Emerging PFAS including Gen-X (HFPO-DA), ADONA and F-53B (9Cl-PF3ONS and 11Cl-PF3OUdS) were not detected in the influent, effluent or biosolids. Interestingly the cyclic PFAS PFECHS was reported to be present in all influent and effluent samples in the Canadian study, although it has not been widely reported in other countries, suggesting a possible widespread alternative use of this substance in Canada.
4. Michigan waste water treatment plants
Helmer et al. (2022) included a detailed study of 10 Michigan WWTPs with industrial pretreatment programs. Their work indicated numerous chemical transformations across the plants that yield effluent PFAS concentrations as much as 19 times greater than influent, attributed to transformations of unmeasured precursors in the influent to measured, stable PFAS in the effluent. PFOA, PFHxA, PFPeA, PFBA, and PFBS show the greatest increases across the plant ranging from 20% to nearly 2,000%. PFOS concentrations decreased across six WWTPs, consistent with a strong tendency to adsorb onto biosolids.
5. PFAS in a waste water network in Uppsala, Sweden
Gobelius et al. (2023) assessed mass flows of 26 PFAS in a waste water network and WWTP in Uppsala, Sweden, to provide insights into their sources, transport, and fate in different treatment steps. PFAS composition profiles and mass flows were used to identify sources within the sewage network. Waste water from one pumping station showed elevated concentrations of C3 – C8 PFCA, likely caused by an industrial source, and two stations had elevated concentrations of 6:2 FTSA, probably originating from a nearby firefighter training facility. Within the WWTP, short-chain PFAS dominated in waste water, whereas long- chain PFAS dominated in sludge.

PFAS Site Profile

Table 1. Case studies (continued).

6. PFAS in an industrial waste water treatment plant, France
Dauchy et al. (2017) studied PFAS in an industrial WWTP receiving raw effluents from a fluorochemical manufacturing facility. PFHxA and nine target fluorotelomers (FTs) were detected in raw effluent from the facility. The overall PFCA mass flow in the raw effluent was negligible compared to the FTs but increased drastically after secondary treatment (through degradation of fluorotelomer precursors) and decreased after the floatation tank (through adsorption onto floatation sludge) but remained at high levels in the final effluent. Similar patterns in mass flow were observed in the FTs, indicating the presence of other unidentified precursors in the raw effluent. Two fluorotelomer PFAS were predominant (6:2 Fluorotelomer sulfonamide alkylbetaine (6:2 FTAB) and 6:2 Fluorotelomer sulfonamide propyl N,N dimethylamine (M4)), accounting for more than 75% of the total PFAS mass flow in the final effluent. While this may be an extreme example of industrial effluent, it demonstrates the persistence of some 'precursor' PFAS through waste water treatment processes.
7. UKWIR Chemicals Investigation Programme, UK
The Chemical Investigations Programme (CIP) is a joint initiative by the UK water industry and regulators in response to current and emerging legislation on trace chemical substances in the water environment. It is managed by United Kingdom Water Industry Research (UKWIR). It involves the investigation of a range of chemical substances, often contained in many domestic products, that find their way into sewage and biosolids and reach rivers and streams. CIP1 (2010 – 2015) investigated the sources/pathways of chemicals getting into rivers via WWTW and characterised treated waste water in terms of these chemicals. CIP2 (2015 – 2020) included further investigation of around 600 WWTW including monitoring chemicals present in effluents and in rivers upstream and downstream of the WWTW discharge points. This monitoring included PFOS and PFOA (but no other PFAS). The study focused on sites with low dilution in the receiving waters. PFOS and PFOA were detected in at least 98% of more than 9,000 effluent samples with a mean of around 0.005 µg/l. Preliminary examinations of fluorocarbon data indicated the presence of significant PFAS concentrations upstream of the WWTW discharge such that, in the overall national context, the inputs from WWTWs have a smaller than expected effect on downstream concentrations. This evidence is contrary to the usual assumption, that holds true for many other substances, that local sewage discharges make at least a significant contribution of trace chemicals to nearby in-river concentrations. Concentrations of PFOS and PFOA upstream of WWTW discharges already exceed the PFOS Environmental Quality Standard (EQS) by a large margin. On average, the concentration of PFOS is reported to be 19% higher downstream of WWTW compared with upstream samples and for PFOA, downstream concentrations are 35% higher (UKWIR, 2021). CIP2 data indicate there are some sites that are subject to important local inputs, either via sewage works or possibly directly to rivers. In particular, there is reasonable circumstantial evidence of the association between aviation activities and markedly higher fluorocarbon concentrations in surface water. However, out of the 609 CIP2 sites, only a handful of locations could be associated with plausible fluorocarbon sources such as airfields, airports or facilities where PFOS might be used in the context of fire prevention. This is a consequence of the CIP site selection process, which did not factor in the investigation of specific types of sites, other than those primarily where WWTW effluent was subject to relatively low dilution in the respective receiving water. It is noted that CIP2 was limited to PFOS and PFOA and does not analyse other PFAS, therefore, it is unclear if concentrations for other PFAS may change the trend shown at CIP2. CIP3 (2020 – 2022) included more detailed investigation to fill some gaps identified in earlier phases, with 16 separate elements planned, reported in 13 volumes. Studies most relevant to this site profile included: *Volume 3 – Groundwater Investigations* 39 different WWTWs were investigated to understand the potential risk to groundwater from effluent discharge. Each site was sampled at four monitoring locations: at effluent as well as one upgradient groundwater and two downgradient groundwater points to capture the effects of the effluent. Samples were analysed for Environment Agency Specific Chemical List – groundwater substances and concentrations upgradient and downgradient of WWTWs were compared to Drinking Water Standards (DWS) as a benchmark for potential non-compliance. *Volume 5 – Substances of Emerging Concern* This study assesses the spatial and seasonal variation of emerging substances in waste water treatment work influent, effluent, and sites in the receiving watercourses both upstream, and downstream of the effluent discharge locations. The report aims to highlight substances with the highest probability of exceeding Predicted No-Effect Concentrations (PNEC), where no EQS values have been set for some substances. The contribution of each of the works to their receiving watercourses was assessed by comparing both upstream and downstream sites to final effluent concentration. Removal efficiencies were calculated by comparing influent and effluent concentrations across monitoring sites. The study included monitoring at 30 WWTW for the following PFAS: PFBS, PFHxS, PFPeA, PFHpA, PFHxA, 6:2 FTAB (referred to as CMDFPAH), 6:2 FTS (referred to as TDFOSA), HFPO-DA (referred to as GENX), with PNECs sourced from the NORMAN Ecotox Database. None of the PFAS were found to exceed their respective PNEC values, however the detailed monitoring data shows the widespread presence of all the PFAS tested in influent, effluent and receiving watercourses. The PFAS with the highest individual concentrations were 6:2 FTAB (up to 1960 ng/l) and 6:2 FTS (up to 780 ng/l). The CIP monitoring shows PFAS were found to be present in the effluent at most WWTW sites, in groundwater samples collected upgradient and downgradient of WWTW sites, and in surface water samples collected upstream and downstream of the WWTW sites. WWTW sites with a larger population equivalent generally have greater influent and effluent concentrations of PFAS than those with a small population equivalent. This is likely due to the potential for a greater number of possible PFAS source sites contributing to waste water in the catchment. PFAS concentrations vary greatly across the WWTW sites such that it is inherently difficult to pinpoint a common contaminant PFAS source site for each WWTW. The factors controlling PFAS in WWTW influent and effluent are likely to be dependent on the type of treatment involved, treatment efficiency and partitioning to sludge.

FTS) and terminal PFAS (PFCAs and PFSAs) through the process. Adsorption to organic matter can show a small degree of removal of PFAS from the aqueous phase with long chain PFAS having higher sorption potentials than shorter chain compounds.

In WWTW with a long history of activity, processes by which PFAS may have become a source of PFAS to the environment include sludge disposal within the site, direct spills and loss to ground, and adsorption to semi-permeable surfaces including infrastructure, pavements and drainage.

5. KEY PFAS CONTAMINANTS OF CONCERN

The composition of PFAS in waste water treatment influent, effluent, sludge and biosolids will depend on the different sources to the WWTW (including industrial and domestic) and the processes within the WWTW. Biological and chemical transformation of precursor PFAS may take place within the WWTW. Physical and chemical partitioning may also take place affecting the composition of PFAS in different media.

The study by Aro et al. (2021) demonstrates the challenge in understanding PFAS in WWTW samples, with evidence for the presence of many more PFAS than can be identified in standard target analysis.

PFCAs and PFSAs are commonly reported in WWTW samples. PFOS and PFOA are the most commonly detected PFAS in WWTW effluent, but they are also the most studied. Studies from the UK and around the world show that even though the use of PFOS and PFOA is now restricted, they continue to be present in WWTW influent and effluent. Sources may include older products still in use (such as treated textiles and carpets), landfill leachates, continued release of PFAS previously adsorbed to semi-permeable surfaces within drainage infrastructure, and recycling of PFAS within the water use cycle. While the overall load of long chain PFAS including PFOS and PFOA may be decreasing, literature studies suggest the load of short chain PFAS is increasing.

Other types of PFAS commonly reported include sulfonamides, fluorotelomer sulfonates, and other fluorotelomer precursors such as alkyl betaines. While these substances are often referred to as precursor compounds, they have also been reported in effluent from municipal WWTPs indicating they are not wholly transformed within the WWTW. The UK CIP3 monitoring demonstrates the occurrence of these substances in effluents from municipal WWTW around England.

6. SOURCE POTENTIAL FOR WASTE WATER TREATMENT WORKS

Following the methodology set out in section 1.3, source potential has been developed for each site profile zone and detailed in Table 2.

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The PFAS Site Profiles were originally prepared by Jacobs for the Environment Agency PFAS Risk Screening Project (Phase 4) and have been edited for publication by CL:AIRE. The authors were Jane Thrasher, Francesca Giacomello, Hugh Masters-Williams, Yolande Macklin, Laura Richmond, Simon Tempest and Hannah Foster.

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Table 2. Site Profile Zone Source Potential.

Site Profile – Zones	Magnitude	Likelihood	Source Potential	PFAS presence and use
Effluent from WWTW	2	5	10	PFAS not treated in the process and released directly to surface water or groundwater. Concentrations of PFAS may increase post treatment. The non-biodegradable PFAAs are not transformed during waste water treatment, instead they remain in the effluent or partition to the sludge. Magnitude of source from individual WWTW sites is assessed as low relative to point source activities.
Influent domestic waste water	2	5	10	Diverse PFAS from multiple consumer users. Includes wash water that could include small amount of PFAS that are now restricted.
Influent trade waste	2	5	10	Currently potential of wide variety of PFAS types and concentrations. PFAS content in trade effluent not regulated by service provider.
Sludge	4	2	8	PFAS are present in WWTW sludge, with long chain PFAS preferentially partitioning into the solid phase. PFAS are likely to be present in sludge disposed to land in past activities within WWTW. This profile does not consider off-site disposal of WWTW solids.
Treatment process	4	2	8	During heavy rainfall events, lagoon overflow may occur with PFAS being transported via overland flow to surface water.
Raw water handling	2	2	4	Tanks containing leachate can leak which can reach surface watercourse via direct runoff.

PFAS Site Profile

IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

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PFAS SP 12
(July 2026)

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Aqueous Film-Forming Foam (AFFF).

Aqueous Film-Forming Foam (AFFF)

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

2. BACKGROUND TO AFFF

Fire-Fighting Foam (FFF), including AFFF, is recognised to be one of the main sources of PFAS loss to the environment impacting ground and groundwater. It is identified as a major potential source at sites such as fire training grounds and fire stations, airfields, oil storage sites, COMAH and other industrial sites with foam fire suppression systems, sites of major fires, as well as potential disposal to landfill and waste effluent. This site profile gives an overview of AFFF to support the site profiles.

2.1 What are Fire-Fighting Foams?

Class B FFF are surfactant solutions used to combat Class B flammable fuel fires, that is, fires involving flammable liquids or flammable gases, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, or alcohols. PFAS fluorosurfactants are added to provide the low surface tension, hydrocarbon repellence and positive spreading co-efficient that enable rapid formation of an aqueous film on the surface of the flammable liquid. The sealing properties of the film prevent the diffusion of flammable vapours and are resistant to burn-back. The chemical stability of PFAS also supports the persistence of the film in fire conditions. While most Class B FFF contain PFAS fluorosurfactants, fluorine-free Class B FFF alternatives are available (Wood Environment and Infrastructure Solutions, 2020). It can be assumed that unless a Class B FFF is specifically described as being fluorine free, it is likely to contain PFAS.

Class B foams have the potential to create an adverse environmental impact if released uncontrolled to the environment, particularly if the foam reaches drinking water sources, groundwater, surface water, or other natural waters. For all Class B foams, including fluorine-free foams, there is a potential for acute aquatic toxicity and excessive biological and chemical oxygen demand, as well as nutrient loading, depending on where the discharge occurs (SWECO, 2020). Wood Environment and Infrastructure Solutions (2020) provide further detail on fluorine-free foam alternatives. Research on fluorine-free foam alternatives continues; for example, one of the novel foam systems produced is derived from polysaccharide copolymers and nanoparticles that are sustainable, non-toxic, and water-soluble (or water-dispersible) (ITRC, 2023a).

Other FFF include Class A foams, which were developed for use on Class A fires, that is, fires involving materials such as wood and paper where the cooling effect of water is of paramount importance in extinguishing the risk. Class A foams are essentially wetting agents that reduce the surface tension of water and allow it to soak into combustible materials more easily. They generally do not contain PFAS chemicals as they are not designed to be film-forming. There is however potential for cross-contamination with PFAS if the same foam forming equipment is used for both Class A and Class B foams. Class A foams are not considered further in this note.

2.2 Types of Class B Fire-Fighting Foams

There are numerous types of foams with different acronyms including those detailed below. These acronyms appear to sometimes be used slightly differently by different manufacturers (e.g. Chemguard and Angus Fire) and authors (Chemguard, 2005; Angus Fire, 2015). Care should be taken with similar acronyms which can mean different things (for example, FFF can be fluorine-free foam but is fire-fighting foam in this document).

The original AFFF started being used in the 1960s. It was a concentrate containing synthetic detergent foaming agent and fluorosurfactants; these are now largely replaced by film-forming fluoroprotein foam (FFFP) but the acronym AFFF continues to be used as a generic term for fluorinated film-forming foam. The various different types of film-forming foams are described below:

- Alcohol resistant aqueous film-forming foam (AR-AFFF) – with additional formulation to make it more suitable for use on polar solvents in addition to hydrocarbons;
- Fluoroprotein foam (FP) – foam concentrate based on hydrolysed natural protein foaming agent, foam stabilisers and preservatives; extensively used in oil and petrochemical industries;
- FFFP – Film-forming foam combining fluoroprotein foam with additional fluorosurfactants developed in the 1980s as a replacement for AFFF; and
- Alcohol resistant film-forming fluoroprotein foam (AR-FFFP) – similar to FFFP but designed for polar solvents.

The acronyms do not relate directly to the type and amount of PFAS in the foam. The specific formulations of FFFs are usually confidential to the companies that produce them, and the formulation of individual manufacturers foams have developed over time (as described further below).

2.3 Application of Fire-Fighting Foams

FFF is applied by mixing foam concentrate with water to make the foam solution, which is then aerated at the nozzle to produce FFF. Foaming systems include aspirators and Compressed Air Foam Systems (CAFS). CAFS may be used for both Class A and Class B foams. FFFs may also be applied via fixed fire suppressions systems (CL:AIRE, 2026m).

2.4 PFAS Formulations in AFFF

The chemistry, history, and production processes for the PFAS that have been used in AFFF are highly complex and there are a large number of potential PFAS present in AFFFs, including both precursors and terminal or arrowhead PFAS. FFF producers consider the ingredients in their products as trade secrets, and Material Safety Data Sheets tend to provide only limited information, for example mentioning PFAS or fluorosurfactants in general, without any specific detail. Most information on the composition of foams comes from researchers testing foams and spills.

Typical AFFF formulations have evolved over time as manufacturers have responded to environmental and health concerns and restrictions, and the description below provides an indication of formulation development over time. AFFF have a long shelf life, and the stocks required to be held in case of emergency are generally substantially larger than the volumes used in operation, maintenance and training, The composition of those held and used in response to incidents may therefore lag behind the composition of those being marketed at the time of the incident.

Further details of PFAS occurrence in FFFs in the EU is provided in the ECHA report of the use of PFAS and fluorine-free alternatives in FFFs (Wood Environment and Infrastructure Solutions, 2020). There is also general information on AFFFs and their use available on the ITRC website (2023b), and in Wood Environment and Infrastructure Solutions (2020). The following sections summarise key information relevant to assessment of AFFF impact in the UK context.

2.4.1 Early Development of AFFF

Fluorosurfactants were first used in FFFs in the 1960s when the United States Navy, supported by 3M, developed AFFF to fight complex liquid fuel fires. The US Navy patented the technology in 1966 (HM Fire Service Inspectorate, 2000).

There were other FFFs in use prior to the development or widespread use of fluorinated foams. For example, in the early 1960s the UK Ministry of Defence installed 'Pyrene' foamers to lay foam blankets on runways at designated sites prior to emergency landings, including as shown, for example, in a 1965 documentary film (Sussex History Forum, 2011). The exact composition of these foams is unknown. The Pyrene company manufactured foam fire extinguishers which used carbon tetrachloride, but it is not known if this technology was also used for foam blankets. Protein foams were also developed and in use prior to the development of fluorinated foams. It seems reasonable to assume that, while the foams visible in the 1965 documentary films that predate the US Navy patent were probably not fluorinated, fluorinated foams are likely to have been adopted by the UK military for use in such runway foaming systems by the late 1960s / early 1970s.

2.4.2 Original AFFF Based on PFOS

The original AFFF were based on PFOS, the C8 PFSA, produced using the electrochemical fluorination (ECF) process. This process results in a complex mixture including around 80% PFOS (linear and branched), plus impurities including PFOA, PFHxS, PFHxA, PFHpA. The use of ECF for producing PFOS was phased out by 3M in the USA in 2002, but may have continued in other countries after this time. In Europe, the use of PFOS in FFFs was restricted under the Marketing & Use Directive (Directive 2006/122/EC, 2006), which required that existing stocks of FFFs containing PFOS should be identified, and their use should be allowed to continue only for a limited time. This allowed FFFs that were placed on the market before 27 December 2006 to be used in England until 27 June 2011.

2.4.3 Replacements for PFOS – Short Chain PFSA

One approach to replacing PFOS in AFFF was to use shorter chain PFSA PFHxS (C6). PFHxS is also produced by the ECF process and is likely to contain similar levels of impurities.

2.4.4 Replacements for PFOS – Fluorotelomer-based AFFF

Another approach has been to use PFAS created using the fluorotelomerisation process. According to ITRC (2023a), fluorotelomer foams have been in use since the 1970s and became the predominant foam after 2001. Fluorotelomerisation cannot be used to produce PFSAs (such as PFOS) but can be used to create PFCAs such as PFOA, and sulfonated fluorotelomers, such as 6:2 FTS. The fluorotelomerisation process creates cleaner products with fewer impurities, however the fluorotelomers can degrade to PFCAs.

The actual chemistry of the fluorotelomers used in AFFF appears to be very variable. Wood Environment and Infrastructure Solutions (2020) lists 22 identified fluorotelomers with varied head groups including betaines and thioamido sulfonates. These range in chain length from 14 carbons (e.g. 12:2 FTAB, with 12 fully fluorinated carbons and 2 nonfluorinated carbons) to 4 carbons (e.g. 4:2 FTS, with 4 fully fluorinated carbons). These precursors appear to transform in the environment into fluorotelomer sulfonic acids including 8:2 FTS and 6:2 FTS. These can transform in turn into PFCAs, for example 8:2 fluorotelomers to PFOA (C8) and shorter, and 6:2 fluorotelomers to PFHxA (C6) and shorter. Environmental monitoring with extended target suites has shown that some of the fluorotelomer precursors can be persistent in soil, waste water, surface water and groundwater; for example the fluorotelomer sulfonamidoalkyl betaine 6:2 FTAB has been found to be locally present in elevated concentrations in various environmental media, with its presence attributed to use in AFFF (Dauchy et al., 2019).

According to ITRC (2023a), legacy 'C8' fluorotelomer AFFFs were manufactured and sold in the USA from the 1970s to 2016. Legacy fluorotelomer-based AFFF foams have historically contained predominantly short-chain (C6) PFAS with formulations ranging from about 50–98% short-chains and the balance as long-chain PFAS (including C8). The long-chain PFAS content of these foams has the potential to break down in the environment to PFOA and other PFCAs, but not to PFOS or other PFSAs.

Over time, manufacturers have developed the fluorotelomer manufacturing process to move away from long chain PFAS (including 'C8'). Modern fluorotelomer foams are based on 'C6' technology which are precursors to 6:2 FTS and short chain PFAS. While they do not contain or breakdown in the environment to PFOS and other long-chained PFAS such as PFHxS and PFOA, foams made with only short-chain (C6) PFAS may still contain trace quantities (parts per billion [ppb] levels) of PFOA and PFOA precursors as by-products of the manufacturing process.

2.5 AFFF Types and Forensic Source Identification

The different manufacturing processes and development of AFFF formulations can be useful for forensic assessment of data and source differentiation, by looking at the relative proportions of PFAS substances present.

ITRC (2023a) suggests that studies show that ECF-based AFFF is the dominant source of PFAS at AFFF-impacted sites in the USA, which is interpreted as being likely to be due to the longer period of ECF-based AFFF use and the relative coincidence of implementation of engineering controls for releases with increased use of telomer-based AFFF. It is not known whether this is also the case in the UK, where there is very limited investigation data, and where testing has been done, it has been focused on PFOS and PFOA. As more data becomes available more evidence is being seen of the presence of locally predominant 6:2 FTS and 6:2FTAB, for example in Environment Agency surveillance monitoring and the UKWIR Chemical Investigation Programme (UKWIR, 2023).

As described above, the ECF process results in a complex mixture of PFCA and PFSA homologues, including both branched and linear isomers. PFOS produced by the ECF process is reported to contain around 70% linear PFOS and 30% branched PFOS (Benskin, et al., 2010). A study by Jiang et al. (2015) reviewed the purity of PFOS and PFOA products believed to have been manufactured by the ECF process in China and found the purity of the PFOS products was between 75–80%, with the major impurity comprising PFOA (more than 10%), also PFHxS, PFHxA and PFHpA. Jiang et al. (2015) found PFOA products were around 95% pure, contained PFOS as the major impurity, and had around 77% linear PFOA to 23% branched PFOA.

In the USA, it is understood that 3M used the ECF process for PFAS manufacture until they phased out its use for the production of C8 PFAS in 2002. The US military specification for AFFF in the 1980s required the use of 3M foams, and there is therefore extensive literature referring to the use of ECF characteristics to differentiate PFAS from military foam usage in the USA from other sources of PFAS or other non-military AFFF which may have been produced by the telomer process. The situation is not so simple in the UK, where there is less clarity on manufacturing processes used for the PFAS products used as the basis of foam formulations by the various national and international foam providers, for military and other uses. It is therefore likely to be more difficult to determine the expected composition of PFAS from different sources in AFFF contaminated sites in the UK.

It is not clear whether other PFAS producers elsewhere in the world (for example China) also used the ECF process, and also which FFF manufacturers were supplied by PFAS producers using the ECF process. The wide range of AFFF recorded by Wood Environment and Infrastructure Solutions (2020) as containing PFSAs including foams produced in the UK by Angus Fire as late as 2007, indicate that ECF foams are likely to have been in widespread use in the UK, including from suppliers other than 3M.

Legacy fluorotelomer AFFF were manufactured and sold in the USA from the 1970s to 2016. It is likely that they were also manufactured elsewhere in the world and sold in the UK during this period. Although not made with PFOA, they contain long chain polyfluorinated precursors (e.g. 8:2 fluorotelomers) which are shown to degrade to PFOA and other PFCAs in the natural environment. They may contain trace quantities of PFOA as an unavoidable by-product of the manufacturing process. Legacy fluorotelomer-based AFFF foams have historically contained predominantly short-chain (C6) PFAS with formulations ranging from about 50–98% short-chains and the balance as long-chain PFAS. The long-chain PFAS content of these foams has the potential to break down in the environment to PFOA and other PFCAs, but not to PFOS or other PFSAs.

Modern fluorotelomer foams marketed as ‘C6 technology’ are based on short-chain PFAS including 6:2 fluorotelomers with the potential to break down to short chain PCFAs (PFHpA and shorter).

Fingerprints relating to the relative distribution of PFAS may be used to investigate and differentiate multiple sources of PFAS release. The type of AFFF used by the US DoD is controlled by Military Specification (MILSPEC), which means that in the USA it may be possible to differentiate some AFFF from military sources from other sources based on the PFAS signature (Higgins, 2021). The PFAS Source Differentiation Guide for Airports (National Academies of Sciences, Engineering and Medicine, 2023) includes a detailed review of PFAS data related to airports and other sources in the USA and proposes PFAS composition may be used to aid source differentiation between airport derived sources of PFAS and other sources. This provides much useful information and insight into the challenges associated with forensic analysis of PFAS. It should be noted that the airport practice and different regulations and supply chain may mean that some findings may be less applicable in the UK.

2.6 Timing of Use of Different AFFF Types

The nature of usage of FFFs is such that in many circumstances users are required to maintain stocks of foam in case of emergency, but the actual rate of usage may be low if no emergency occurs. The stability of PFAS means that they tend to have a long shelf life and therefore phasing out of specific types of PFAS by the manufacturer does not directly equate to cessation of use of those AFFF by the end operators, except in the case of specific regulatory restrictions.

The chemical nature of PFAS also means that they are difficult to fully remove from equipment when transitioning to a new supply. This can result in ‘crossover’ of legacy PFAS compounds in equipment and washwater. It is not known how much effect this may have for example in transitioning equipment between fluorinated foams, and fluorine-free foams for training exercises or Class A fires.

2.7 Published Data on Fire-Fighting Foam

Wood Environment and Infrastructure Solutions (2020) undertook a desk study to identify PFAS present in FFFs with information sources including literature review and supplier information. Most information on PFAS was found within the scientific literature as they discovered that supplier information and safety data sheets only indicated general terms such as ‘fluorinated surfactant’. They concluded that a large number of highly diverse PFAS substances

were found in the context of use in FFFs. They uncovered very little specific information on testing of specific foams, apart from a study by KEMI (2015). The findings are consistent with the discussion above.

KEMI (2015) published the results of chemical analysis of eight selected FFFs on the Swedish Market in 2014. They included targeted analysis of known PFAS substances, and non-targeted analysis. The targeted analysis found the most common detections were short chain PFCAs, with highest concentrations of PFHxA. The fluorotelomer 6:2 FTS was present at high concentrations in all products. Long chain PFCAs and PFSAs were less frequent and at lower concentrations. The non-targeted analysis found fluorinated telomer products with 6:2 configuration present in the mg/kg range. These results are consistent with the description of modern fluorotelomer AFFF.

3. PROCESS

AFFF is used in many processes and activities, refer to specific site profiles for further details. Some processes and activities by which AFFF may be released into the environment include:

- Use in training exercises including practicing emergency response;
- Large volume accidental loss through systems failure including foam suppressions systems;
- Low volume accidental release during storage, transfer and maintenance including vehicle washing;
- Incident and emergency response to fires;
- Incident and emergency response to flammable fluid spills for vapour suppression;
- Discharge to drain or ground;
- Controlled or uncontrolled waste disposal; and
- Slow release of AFFF previously adsorbed to concrete and other permeable surfaces during prior release.

Land uses with the potential for AFFF release include (but are not limited to):

- Airports and airfields (military and civilian);
- Fire stations and fire training grounds;
- Large industrial sites including COMAH sites, refineries, steelworks, ports;
- Small industrial sites with fire suppressions systems;
- Fuel storage sites; and
- Sites of major fires where foams have been used.

4. KEY PFAS CONTAMINANTS OF CONCERN

A wide spectrum of PFAS precursors and terminal degradation products may be present associated with AFFF use and loss to the environment.

Wood Environment and Infrastructure Solutions (2020) lists the following PFAS associated with AFFF:

- PFSAs: C2 – C11;
- PFCAs: C4 – C14 and C18;
- Various perfluoroalkane sulfonyl fluoride substances (PASF) including sulfonamides; and
- Fluorotelomers: 22 substances including sulfonates, alcohols, betaines, etc.

The actual PFAS present at any one site will vary dependent on the AFFF formulations used, which will have varied over time. While some generalities may be drawn associated with the dates of operation and use, and the date of phasing out of PFOS-based AFFF and the introduction of fluorotelomer chemistry, actual practice varied. Records of AFFF type and composition are also likely to be poor.

Fingerprints relating to the relative distribution of PFAS may be used to investigate and differentiate multiple sources of PFAS release.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as “ITRC (2023)” was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		

PFAS Site Profile

PFAS Site Profiles were developed as part of the Environment Agency PFAS Risk Screening Project and represent an understanding of PFAS uses and occurrences from specific industry sectors at the time of writing in March 2024. This profile focuses on Civil and Military Airfields and Airports.

Fire Suppression Systems

1. INTRODUCTION

1.1 Overview

Per- and poly-fluoroalkyl substances (PFAS) are a broad group of more than 12,000 synthetic fluorinated organic chemicals. PFAS have been used in a wide variety of consumer products and industrial applications since the 1940s because of their unique chemical and physical properties, including oil, water and stain repellence, temperature and chemical resistance, and surfactant properties. These properties mean they are also extremely persistent in the environment. Some PFAS are bio-accumulative and toxic, and/or highly mobile.

Increasing awareness of the widespread presence of PFAS has heightened regulatory concerns about their potential risks to human health and the environment. To ensure effective actions are implemented the Environment Agency needs to better understand the potential sources of PFAS, the mechanisms of transport (pathways) and the relative significance of these substances in the environment.

As part of the Environment Agency PFAS risk screening project (Phases 1 to 4 carried out between 2020 to 2025) Jacobs developed individual site profiles for several potential high risk site types. They focus on specific industry sectors, representing potentially important sources of PFAS, whether from use or manufacture, with the potential for release into the environment.

The primary aim of these profiles is to help those parties involved in the regulation, investigation and remediation of sites where these problem chemicals present a risk to health and the wider environment. These are not definitive studies, but they introduce some of the technical considerations that need to be borne in mind when assessing a particular type of facility. Representing an understanding of PFAS at the time of writing (March 2024) and with published literature notably increasing continuously as practitioners and regulators seek to improve their understanding of PFAS, users must make their own appropriate assessments with current knowledge and specific to their site.

The reader is referred to Ross and Hurst (2019) and ITRC (2023) for more detailed information on PFAS chemistry, properties, fate and transport, risk assessment and remediation, to Glüge et al. (2020) for a review of the diversity of uses of PFAS, and to Ross (2023) for an overview of the uses of PFAS to assist with identification of sites of concern.

1.2 Site Profile Selection and Preparation

The site types for which site profiles have been developed in this project have been selected to represent potentially important users and sources of PFAS release to the environment in terms of quantity, frequency and historical records available.

Technical and scientific publications, fact-sheets, regulations, product websites, articles and online newspaper reporting interviews on the PFAS discussions were researched and reviewed to obtain information on the use of PFAS, with particular reference to the United Kingdom.

Each site profile includes site background information focused on PFAS use and identification of specific zones (where applicable), description of the processes involving PFAS, types of PFAS likely to be present, and an indication of the impact to water and soil. Brief examples and case studies from the literature are also provided.

For each site type a number of zones or activities have been identified where PFAS may be used. It should be recognised that not every site of this type will have all the activities identified. For example, a fire station site may be anything from a building where fire tenders containing Aqueous Film-Forming Foam (AFFF) are based (but filling, maintenance and training happen elsewhere) to a hub with a wide range of activities such as fire practice training, concentrate storage etc. in addition to vehicle storage.

Site profiles have been created for the following site types identified as potentially important potential sources of PFAS release to the environment:

- Civil and Military Airfields and Airports;
- Control of Major Accident Hazards (COMAH) Regulated Sites;
- Fire-fighting Grounds and Fire Stations;
- Landfills;
- Metal Manufacturing and Finishing;
- Military Bases (other than Air Transport Sites);
- Oil and Gas Industry (onshore exploration and extraction operations);
- Paper and Cardboard Manufacturing;
- Refineries and Fuel Sites;
- Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) Manufacturing; and
- Waste Water Treatment Works.

Additional site profiles which do not relate directly to a particular site type have been developed for the following subject areas, which have potential applications within many different site types:

- Aqueous Film-Forming Foam (AFFF); and
- Fire Suppression Systems.

2. BACKGROUND TO FIRE SUPPRESSION SYSTEMS

Fire suppression systems do not directly relate to a particular site type. This site profile has been developed to cover fire suppression systems which have the potential to be in use on many sites.

Foam suppression systems are fixed sprinkler systems commonly used in large areas where there are a lot of flammable or combustible liquids, including flammable liquid storage, processing areas, warehouses, hangars and marine applications. Fire-fighting foam including AFFF is commonly used in fire suppression systems, (refer to the site profile overview for AFFF (CL:AIRE, 2026l)). This can include fluorinated foams containing PFAS, and fluorine-free foams. Not all fixed fire suppression systems use foam, with gas systems and water systems also used for specific applications. Not all foam systems contain PFAS.

2.1 Fire Suppression System Design and Operation

Foam suppression systems are designed to combine water and foam and discharge it rapidly for large scale fire extinguishment, for example with high expansion foam a large warehouse or hangar can be filled with foam in seconds. The foam suppresses and smothers fire and vapours and prevents re-ignition. The foaming agent is stored separately from the water supply and the two are mixed within the piping system prior to discharge. The design of the foam suppression system will depend on many factors including, but not limited to, the size of the facility, the hazard area and the assets being protected. All systems require a water supply, a foam concentrate tank, and a means of transferring the water and foam mixture to the required discharge point under pressure to achieve the high volumes required for rapid extinguishment. The pipework may be above or below ground. In smaller systems the foam concentrate may be added close to the point of discharge, but on large sites the foam mix may be distributed around the site under pressure. As detailed below, this results in the potential for rapid release of a significant volume of foam in the case of system failure or accidental discharge.

Foam suppressions systems should be designed to include the containment and suitable disposal of discharged fluids, including discharges during maintenance and testing as well as emergency response, in accordance with the British Standard BS 5306 (BSI, 1998) or other relevant standards. Contained fluids may then be discharged to the site waste-water treatment system, or the foul sewer. It is understood that PFAS are currently not generally considered within discharge consents, and site water treatment systems are not designed for, and are generally ineffective at, removing PFAS. It is therefore likely that PFAS are being discharged to the foul water network from these sites without currently needing to be regulated.

Fire suppression systems are designed for emergency use, therefore the majority of the PFAS in use in such systems is expected to remain unused. The systems do however require regular inspection, testing and maintenance, which may or may not require discharge of foam. Full scale demonstrations may also be required as part of emergency practice required under COMAH (refer to the site profile for COMAH sites (CL:AIRE, 2026b)). According to the European Chemicals Agency (ECHA, 2015), any foam that is consumed in such exercises should be restored to the required minimum storage volume using fresh foam concentrate. Foams have a typical shelf life of around 20 years, therefore there is no need to remove and replace foams on a regular basis. This may result in fixed foam systems continuing to hold foam types which have been withdrawn from general use, and also containing mixtures of old and new foam stocks. For example, while restrictions are now in place to prevent the selling of foams containing PFOA, there are derogations in place to permit the continuing use of existing stocks for 20 years after the restriction comes into place. It should be noted also that PFAS adsorb onto surfaces and are particularly difficult to remove. There is therefore potential for cross-over and some PFAS to remain in systems where fluorinated foams had been used in the past, even if they are no longer used in the system. Testing is therefore required to verify the composition of foam that may be discharged from a system, even if the operator can provide information on the foam concentrate that is currently being used to top-up the system.

2.2 Fire Suppression System Applications

It is understood that the use of fixed foam fire suppression systems is not specifically mandated in regulations, however they may be required for insurance purposes, for compliance with fire prevention requirements under COMAH (refer to the site profile for COMAH sites (CL:AIRE, 2026b)), or with Environmental Permitting Regulations (as part of the fire prevention plan). It is expected that they are in widespread use in the UK, not only at COMAH sites, but also at other industrial and commercial sites. Online marketing information for foam fire suppression systems indicates their use in the following sectors:

- Refineries;
- Aircraft hangars;
- Jet engine testing facilities;
- Warehouses;
- Marine applications;
- Processing areas;
- Flammable liquid storage;
- Petro-chemical tank farms;
- Liquefied natural gas storage;
- Loading docks;
- Conveyors; and
- Tunnels.

2.3 Use of Fluorinated AFFF in Fire Suppression Systems

There is evidence for widespread use of fluorinated AFFF in fire suppression systems, and also that this use represents a large proportion of the total stock of AFFF held in Europe and the UK. A report for the Irish EPA (SWECO, 2020) reviewed the use of AFFF in the Republic of Ireland, surveying site operators and users to obtain information on current and past use. While uptake of the survey was somewhat limited, the report provides a picture of AFFF use in industry in Ireland in 2020. They found that automated fire suppression systems accounted for around 70% of the total stock of PFAS-containing foams identified in the survey. This was associated with fuel and solvent storage facilities at power plants, fuel terminals and other storage facilities and pharmaceutical facilities.

System failure can be a common cause of incidents involving releases to the ground/drainage system associated with foam fire suppression systems.

2.4 Examples of Accidental Releases

Aircraft hangar systems appear particularly prone to accidental discharge, with the potential for very large volumes of foam being discharged rapidly. A study was undertaken by the University of Maryland (UMD) in 2019 (UMD, 2019) after concerns were raised over the tendency for these systems to inadvertently discharge causing significant life safety issues, property damage, major financial and environmental impacts. UMD surveyed insurance companies, operators, and the national air transportation association. One hundred and seventy-four incident reports of foam discharges over the last 16 years, both in response to fires and accidental discharge, were received from 11 sources, mostly reported by insurance companies. The majority (85%) of reports received were from the USA. The remaining 15% of reports originated from 8 other (unnamed) countries. Of the 174 incidents of foam discharge from such systems during the period 2004 – 2019, 37 incidents were where the foam system had discharged in response to a fire and 137 incidents were where there was an accidental foam discharge. Accidental discharge of foam from hangars can result in substantial environmental damage as the foam is likely to be discharged to surface water drainage systems or to soft ground where infiltration to groundwater may occur. Documented examples of environmental damage associated with accidental hangar foam discharge include Schiphol Airport and Toronto Airport.

The 2019 survey in the Republic of Ireland (SWECO, 2020) also gathered data on accidental discharge of foam including from fire suppression systems. They gathered data from eight respondents citing 10 incidents over the period 2006 to 2020, mostly referencing accidental losses from fixed systems. These include accidental discharge during system commissioning, testing and maintenance, activations during project work and false activation at a tank farm. The releases were generally captured in dedicated onsite retention facilities, or discharged to the site waste water treatment plant or foul sewer. The quantities of foam released were reported to be fewer than 20 litres of concentrate in each case.

Two examples of incidents of the release of AFFF from fire suppression systems in England have been identified from Environment Agency records. These incidents were not identified by systematic review and it is not known how common such incidents are in the UK. These are detailed further below.

One incident was reported by a chemicals manufacturer at a site which is both a COMAH site and a regulated installation under EPR. The operator noted a leakage of the 'underground foam ring main system' which occurred during routine testing of the fire protection system. Some of the foam leaked into the surface water discharge system which discharges to the local estuary. Although the leakage to the drainage system was spotted quickly and stopped within 30 minutes, it was estimated that up to 2 tonnes of foam and water had been released to the surface water drainage system and the estuary. The foam in question was identified as a 'C6' AFFF that does not contain the regulated PFOS or PFOA, however is likely to have contained 6:2 FTS and a precursor of PFHxA and other short-chain PFAS.

The other incident was identified on the Environment Agency National Incident Reporting System, and described accidental damage to a sprinkler system as a result of a collision with a vehicle, and the loss of about 400 litres of AFFF foam mixed with water (50/50), some of which entered drains. The business in question appears to be a relatively small printer ink factory, and not a COMAH site or regulated installation under EPR. This example illustrates the potential for widespread use of foam concentrates in fire suppression systems and potential for accidental loss. It also highlights the potential for foam use by relatively small industrial users which might not have been picked up in the reported national surveys.

3. CASE STUDIES

Three sites were reviewed as case studies with the findings listed in Table 1.

4. PROCESS

Fire suppression systems may result in the release into the environment from the following:

- Commissioning, routine testing and maintenance;
- Use in training exercises including practice emergency response;
- Incident and emergency response;
- Large volume accidental loss through systems failure;
- Low volume accidental release during storage, transfer and maintenance;
- Discharge of contained fluids via waste water treatment systems or direct to foul sewer, drain, surface water or ground;
- Controlled or uncontrolled waste disposal; and
- Slow release of AFFF previously adsorbed to concrete or other porous surfaces during prior release.

Table 1. Case studies.

1. Schiphol Airport, Netherlands
In July 2008, an error in the sprinkler-system at a hangar at Schiphol-Oost released 10,000 litres of AFFF, containing 143 kg of PFOS, into the surrounding environment (Nordic Council of Ministers, 2019). The release spread into waste water reservoirs, which then leaked and caused substantial contamination of soil and surface water. Contaminated soil from this incident also resulted in delays of over a year to a project to build a new bus lane in Schiphol-Oost in 2017. Over 50,000 m^3 of the soil dug up was found to be contaminated and thus difficult to dispose. Nordic Council of Ministers (2019) reported the cost of remediation was estimated as €30–40 million.
2. Toronto International Airport, Canada
According to Awad et al. (2011), in June 2000, a fire alarm at an airline hangar at Toronto International Airport malfunctioned, releasing 22,000 litres of PFOS-containing AFFF and 450,000 litres of water from the sprinkler system into the storm sewers. The AFFF passed through catch basins and storm sewers before being discharged into a nearby creek. The total quantity of perfluorinated compounds released was estimated at 330–1650 kg.
3. Tank farm at a former industrial complex, UK
This case study is based on a conference presentation (Ogden, 2022). A former industrial complex located in a rural setting of the UK was being redeveloped. The site consisted of a hydrocarbon processing plant including a tank farm with a fire suppression system including foam pourers. AFFFs were used on site but the formulations of AFFFs were not known. The fire systems were tested regularly, and foams were released to the site drainage network via sumps into bunds. The site was decommissioned and at the time of the study consisted of stockpiles of demolished bund walls, plinths and lumps of concrete of varying size from large slabs to powder. Base slabs remained in place. PFAS were identified in soil and groundwater from initial tests and therefore an investigation was carried out to establish whether the demolished concrete and base slab were contaminated with PFAS. Stockpile arisings and base slabs were sampled and tested for PFAS. Unmilled samples contained leachable amounts of PFAS but a risk assessment concluded that the concentrations were not so high as to cause unacceptable pollution to the environment. Base slab core samples were found to be contaminated with PFAS at the top and the bottom of the core but not in the middle which suggested potential secondary contamination of the base of slab from rising groundwater contaminated with PFAS. The case study demonstrates that activities associated with testing and maintenance of a fire suppression system can result in PFAS contamination including concrete used in bunds.

Land uses with the potential for foam fire suppression systems include (but are not limited to):

- Fuel storage sites;
- Airports and airfields (military and civilian) including hangars and fuel stores;
- Large industrial sites including COMAH sites, refineries, steelworks;
- Small industrial sites with fire suppression systems;
- Ports and docks; and
- Warehouses, conveyors, tunnels.

Waste water and sewerage systems receiving discharge and runoff from such facilities may also be impacted.

5. KEY PFAS CONTAMINANTS OF CONCERN

A wide spectrum of PFAS precursors and arrowhead products may be present associated with AFFF used in foam fire suppression systems (refer to the site profile for AFFF (CL:AIRE, 2026l)).

The actual PFAS present at any one site will vary dependent on the AFFF formulations used. Since the expectation is that the foam suppression system will not be used, and AFFF has a typical shelf life of 20 years, fire suppression systems may contain stocks of AFFF types which have since been withdrawn from the market due to environmental concerns. Systems do require regular top-up to replace concentrate consumed in testing and maintenance and may therefore contain mixtures of formulations. Also, the tendency of PFAS to adsorb to surfaces means that it is difficult to remove all PFAS from pipework and even if the system is drained with the intention of removing old foams, some cross-over may occur. This all means that testing is required to demonstrate the composition of the foam within a system, and while the operator may know the composition of the foam currently being used to top-up the system, this may not be representative of the composition that may be discharged.

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IMPORTANT NOTES FOR READERS OF THE PFAS SITE PROFILES

The PFAS Site Profiles are based on available online literature and review of readily available technical publications at the time of writing (2020-2024). The authors recognise that additional information may be available that has not been used in this study.

The published literature on PFAS occurrence and distribution is vast and continually expanding. For example, the Interstate Technology and Regulatory Council web resource cited in the PFAS Site Profiles as "ITRC (2023)" was substantially updated in January 2026.

The purpose of the PFAS Site Profiles is to provide regulators and other interested parties with researched advice on how to assess problem sites that may be impacted by legacy use or release of PFAS. The profiles do not seek to address the specific circumstances of

each site as these will be unique. As such, the PFAS Site Profiles should be read with the following reservations in mind:

- Practices can vary between different sites and therefore individual sites may not have been exposed to the typical PFAS contaminants of concern as detailed in each site profile;
- Site exposure to PFAS contaminants of concern may vary based on practices and equipment used on site; and
- Given the longevity of PFAS in the environment, site profiles may refer to practices which are no longer followed, and subsequently may omit current practices which avoid contamination.

DISCLAIMER

The information, views and conclusions drawn concerning the PFAS Site Profiles are based, in part, on information supplied to Jacobs by third parties; and from publicly available information. Jacobs has proceeded in good faith on the assumption that this information is accurate and complete. Jacobs accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to Jacobs by third parties or available from public sources.

All users must make their own appropriate assessments specific to their site (or group of sites).

For the avoidance of doubt none of CL:AIRE, Jacobs or the Environment Agency accept liabilities resulting from the use or interpretation of the contents of the PFAS Site Profiles.

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PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

Note: this list of acronyms and abbreviations includes those used across all the site profiles and therefore may include some acronyms and abbreviations not used within this profile.

General Acronym / Abbreviation	Definition	General Acronym / Abbreviation	Definition
AFFF	Aqueous Film-Forming Foam	HSE	Health and Safety Executive
ALARP	As Low As Reasonably Practicable	ITRC	Interstate Technology and Regulatory Council
AR-FFFP	Alcohol resistant film-forming fluoroprotein foam	LCMS	Liquid Chromatography Mass Spectrometry
BOW	Bilge and oily waste water	LPG	Liquified Petroleum Gas
CA	Competent Authority	MAPP	Major accident prevention policy
CAS	Chemical Abstracts Service	MILSPEC	Military Specification
CAFS	Compressed Air Foam System	MSDS	Material Safety Data Sheets
CDOIF	Chemical and Downstream Oil Industries Forum	NAPL	Non Aqueous Phase Liquid
CIMAH	Control of Industrial Major Accident Hazards	NCM	Nordic Council of Ministers
CIP	Chemicals Investigations Programme	NIHHS	Notification of Installations Handling Hazardous Substances Regulations
CLP	Classification Labelling and Packaging	NORM	Naturally occurring radioactive material
CO_2	Carbon dioxide	OECD	Organization for Economic Cooperation and Development
COMAH	Control Of Major Accident Hazards	ONR	Office for Nuclear Regulation
CPI	Confederation of Paper Industries	PCM	Paper and Cardboard Manufacturing
DoD	Department of Defence (Australia)/Defense (USA)	PNEC	Predicted No-Effect Concentrations
DoE	Department of Environment	PPB	Parts Per Billion
DWS	Drinking Water Standards	PPE	Personal protective equipment
ECF	Electrochemical fluorination	RAAF	Royal Australian Air Force
EOF	Extractable Organic Fluorine	REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EPA	Environmental Protection Agency (for Denmark)	STM	Surface treatment of metals
EPR	Environmental Permitting Regulations	TOP	Total Oxidisable Precursor
EQS	Environmental Quality Standard	TULAC	Textiles, Upholstery, Leather, Apparel and Carpets
EU	European Union	UBA	Umwelt Bundesamt (German Environment Agency)
FCM	Food Contact Material	UK WIR	United Kingdom Water Industry Research
FFF	Fire-Fighting Foam	UMD	University of Maryland
FFFP	Film-Forming Fluoroprotein	US EPA	United States Environmental Protection Agency
FP	Fluoroprotein	WWTP	Waste Water Treatment Plant
FPP	Fire Prevention Plans	WWTW	Waste Water Treatment Works
FRS	Fire and Rescue Service		

PFAS Site Profile

ACRONYMS AND ABBREVIATIONS

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PFAS Acronym / Abbreviation	PFAS Definition	PFAS Acronym / Abbreviation	PFAS Definition
10:2 FTOH	10:2 Fluorotelomer alcohol	HFPO-DA	Hexafluoropropylene oxide-dimer acid
10:2 FTS	10:2 Fluorotelomer sulfonate or sulfonic acid	HFPO-TA	Hexafluoropropylene oxide-trimer acid
10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids	MeFOSAA	Methylperfluorooctanesulfonamidoacetic acid
11Cl-PF3OUdS	11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B Minor)	PAP	Polyfluorinated alkyl phosphates
12:2 FTS	12:2 Fluorotelomer sulfonate or sulfonic acid	PASF	Perfluoroalkane sulfonyl fluoride substances
14:2 FTS	14:2 Fluorotelomer sulfonate or sulfonic acid	PFA	Perfluoralkoxy polymer
12:2 FTAB	12:2 Fluorotelomer sulfonamido betaine	PFAA	Perfluoroalkyl acid
4:2 FTS	4:2 Fluorotelomer sulfonate or sulfonic acid	PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
5:3 FTCA	5:3 Fluorotelomer carboxylic acid	PFBA	Perfluorobutanoate or Perfluorobutanoic acid
6:2 FTAB	6:2 Fluorotelomer sulfonamidoalkyl betaine (see also CMDFPAH)	PFBS	Perfluorobutyl sulfonate or Perfluorobutyl sulfonic acid
6:2 FTCA	6:2 Fluorotelomer carboxylic acid	PFC	Perfluorinated Compound
6:2 FTOH	6:2 Fluorotelomer alcohol	PFCA	Perfluoroalkyl carboxylic acid
6:2 FTS	6:2 Fluorotelomer sulfonate or sulfonic acid (see also TDFOSA)	PFDA	Perfluorodecanoate or Perfluorodecanoic acid
6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids	PFDoA	Perfluorododecanoate or Perfluorododecanoic acid
6:2 diPAP	6:2 Fluorotelomer phosphate diester	PFECA	Perfluoroalkyl ether carboxylic acid
8:2 Cl-PFESA	8:2 Chlorinated perfluoroalkyl ether sulfonic acid	PFECHS	Perfluoroethylcyclohexane sulfonate
8:2 FTOH	8:2 Fluorotelomer alcohol	PFESA	Perfluoroalkyl ether sulfonic acid
8:2 FTS	8:2 Fluorotelomer sulfonate or sulfonic acid	PFHpA	Perfluoroheptanoate or Perfluoroheptanoic acid
8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids	PFHpS	Perfluoroheptane sulfonate or Perfluoroheptane sulfonic acid
9Cl-PF3ONS	9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F-53B Major)	PFHxA	Perfluorohexanoate or Perfluorohexanoic acid
ADONA	4,8-Dioxa-3H-perfluorononanoic acid	PFHxS	Perfluorohexane sulfonate or Perfluorohexane sulfonic acid
CMDFPAH	Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide; a synonym of 6:2 FTAB used in UKWIR reports	PFNA	Perfluorononanoate or Perfluorononanoic acid
EtFOSA	N-ethyl-perfluorooctane sulfonamide	PFOA	Perfluorooctanoate or Perfluorooctanoic acid
EtFOSAA	N-ethyl-perfluorooctane sulfonamido acetic acid	PFOS	Perfluorooctane sulfonate or Perfluorooctane sulfonic acid
EtFOSE	N-ethyl-N-(2-hydroxyethyl) perfluorooctane sulfonamide	PFOSA	Perfluorooctane sulfonamide (FOSA)
F-53B	Trade name for chlorinated polyfluoroalkyl ether sulfonic acids (9Cl-PF3ONS and 11Cl-PF3OUdS)	PFOSE	Perfluorooctane sulfonamido ethanol
FASA	Perfluoroalkane sulfonamide	PFPA	Perfluoropentanoate or Perfluoropentanoic acid
FBSA	Perfluorobutane sulfonamide	PFPE	Phosphate ester salts
FOSA	Perfluorooctane sulfonamide	PFPeA	Perfluoropentanoic acid
FOSAA	Perfluorooctane sulfonamidoacetic acid	PFPeS	Perfluoropentane sulfonate or Perfluoropentane sulfonic acid
FOSE	Fluorooctane sulfonamido ethanol	PFPS	Perfluoropentane sulfonate
FTCA	Fluorotelomer carboxylic acid	PFSA	Perfluoralkane sulfonic acid
FTMAC	Fluorotelomer methacrylate	PFUnDA	Perfluoroundecanoate or Perfluoroundecanoic acid
FTOH	Fluorotelomer alcohol	POSF	Perfluorooctane sulfonyl fluoride
FTS	Fluorotelomer sulfonate	PTFE	Polytetrafluoroethylene
FTSA	Fluorotelomer sulfonic acid	TDFOSA	3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctane-1-sulfonic acid; a synonym for 6:2 FTS used in UKWIR reports
Gen-X	Trade name for HFPO-DA		